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Intra Day Bid-Ask Spreads, Trading Volume and Volatility: Recent Empirical Evidence from the London Stock Exchange

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1. INTRODUCTION

The advent of high frequency data sets and readily available powerful computing have provided finance researchers with the enviable opportunity of being able to explore stock market phenomena at the finest levels of data. For the first time in the history of the subject, researchers do not have to make assumptions regarding the nature of the underlying distributions because they can now access them first hand. An interesting analogy occurred at the end of the 19th century. Before the birth of photography a debate raged as to whether horses had all four feet off the ground when they galloped. With an absence of suitable data, the debate was founded on assumptions, potential theoretical flaws, etc. The debate was brought, however, to a close when a photographic experiment involving a large number of synchronised cameras was able to provide

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conclusive evidence that horses do indeed have all four feet off the ground when they gallop.[1] The availability of high frequency data and powerful computing offers finance researchers the same degree of potential insight.

The high frequency research to date has offered a number of insights, especially in terms of the US markets. For example, returns and returns volatility have been found to be greater at the open and close of the trading day and, as a consequence, exhibit a U-shaped pattern (McInish and Wood, 1985; Wood, McInish and Ord, 1985; Harris, 1986; Jain and Joh, 1988; McInish and Wood, 1990; and Madhavan, Richardson and Roomans, 1997). The U-shaped intra day patterns have also been documented in bid-ask spreads (McInish and Wood, 1985; and Abhyankar et al., 1997), and trading volume (Jain and Joh, 1988; McInish and Wood, 1990; and Atkins and Basu, 1995).

Although most of the high frequency research to date has concentrated on the mechanisms of US stock markets, other markets are being increasingly researched. Intra day effects have been documented for the London Stock Exchange (LSE) (Yadav and Pope, 1992; Kleidon and Werner, 1993; Abhyankar et al., 1997; Naik and Yadav, 2000; Taylor et al., 2000; Ellul, 2001; and Ellul, Shin and Tonks, 2002), the Hong Kong Stock Exchange (Ho and Cheung, 1994; and Cheung, 1995), the Tokyo Stock Exchange (Hamao and Hasbrouck, 1995), and the Toronto Stock Exchange (McInish and Wood, 1990).

Given the potential insights to be offered by high frequency data the International Institute of Banking and Financial Services at the University of Leeds is funding a major project into the micro structure of the LSE. To date high frequency stock market data and all associated news data have been, and are continuing to be, assembled and further work is being undertaken on adding accounting, ownership and board level data. Given that this is the first full paper (Wang et al., 2000, produced a short note on the distributional properties of the data) of a large, ongoing research programme, it has a number of exploratory objectives. First, it measures and documents a wide range of stock market characteristics. This empirical work is undertaken from the perspective of very high frequency 1 minute interval data, whereas most of the prior work has been

based on 15 minute interval data. The results of the paper are based on a data set consisting of 25 million observations. Second, it derives results from the LSE and this complements the largely US based literature and some of the more recent work on the LSE. There are major institutional differences between the UK and US stock markets which may possibly alter the intra day patterns. For example, there is a higher proportion of institutional investors in the UK than in the US (Short and Keasey, 1999). Similarly, the mixture of order-driven and quote-driven systems in the UK may affect the trading characteristics of the market. Third, it compares the characteristics of different trading systems. The LSE introduced an order driven system (SETS) for highly liquid shares in October 1997. The paper explores whether shares traded in the SETS and non-SETS systems have different intra day patterns. These findings complement the recent work of Naik and Yadav (2000), Taylor et al. (2000), Ellul (2001) ad Ellul et al. (2002) on the impact of SETS.

This paper is organised as follows. Section 2 provides an overview of empirical evidence of the intra day pattern. Section 3 outlines briefly the institutional settings of the LSE which are relevant to the current research. Section 4 introduces the data and methodologies, and Section 5 reports the empirical results. Finally, Section 6 offers conclusions.

2. A REVIEW OF THE EMPIRICAL LITERATURE

As noted in the introduction, the intention of the current paper is to describe the results of exploring a rich, new data set and to lay the foundations for future theoretical and empirical work. Although the paper does not conform to the now standard model of empirical research in finance (namely, the testing of formalised hypotheses), the exploration is guided by a brief review of the existing empirical literature. The empirical literature is reviewed under the headings of a number of key market variables.

(i) Intra Day Bid-Ask Spreads

Brock and Kleidon (1992) and Lee, Mucklow and Ready (1993) documented that the intra day width of bid-ask spreads for

NYSE stocks follows a U-shaped pattern. Madhavan, Richardson and Roomans (1997) developed a structural model of intra day price formation and showed that the bid-ask spread of NYSE stocks is U-shaped. The U-shaped pattern in spreads was also observed in the LSE (for example, Abhyanhar et al., 1997) and the Stock Exchange of Hong Kong (for example, Ahn and Cheung, 1999).

In contrast to the U-shaped patterns noted above, McInish and Wood (1992) found a crude reverse J-shaped pattern in minute-by-minute bid-ask spreads for NYSE stocks. Chan, Christie and Schultz (1995), however, found that the bid-ask spread for NASDAQ securities is relatively stable throughout the day but narrows during the final hour of trading. Kleidon and Werner (1993), using a sample of cross-listed securities on the LSE and US exchanges, reported that intra day spreads during the Mandatory Quote Period (hereafter MQP)[2] decline across the trading day. Whereas, Naik and Yadav (2000) found no significant intra day variation in spreads for non-SETS stocks but sharply declining spreads at the start of the trading day for SETS stocks. Ellul et al. (2002) find a narrowing of spreads throughout the day is a feature of both SETS and non-SETS stocks.

Although explanations have been given for the various patterns of spreads in multi-dealer systems,[3] of direct interest here are the discussions concerning the impact of SETS on spreads. As noted by Naik and Yadav (p. 8, 2000) the introduction of the SETS order book system was expected to benefit investors through the ability to post limit orders, to have real time knowledge of the price and quantity details of deals flowing through the order book and to benefit from lower order processing costs. However, Naik and Yadav (2000) note that spreads have increased very sharply in the first hour of trading for SETS stocks and, therefore, dealers may have provided a useful stabilisation role in the opening of the market which is missing in the order system of SETS.[4] Indeed, Ellul (2001) and Ellul et al. (2002) argue that a dealership system fulfils a useful complementary function to order book systems by providing back-up liquidity which is particularly useful for small stocks and for thinly traded large stocks.

(ii) Intra Day Volume

Wood, McInish and Ord (1985), Jain and Joh (1988), Foster and Viswanathan (1990), McInish and Wood (1990) and Gerety and Mulherin (1992), in papers dealing with the NYSE and NASDAQ, showed that trading volume (measured as the number of shares traded) also follows a U-shaped pattern during the trading day. Gerety and Mulherin (1992) showed that overnight volatility can cause increased volume at the open and close of the stock market. Atkins and Basu (1995) examined the public announcements after trading hours of 400 NYSE stocks and found that public information also appears to have a significant effect on the U-shaped pattern of volume. This indicates that the large volume at the beginning of the day could be the result of the aggregate amount of new information that becomes known overnight.

Abhyankar et al. (1997), however, found that for the LSE, trading volume is not U-shaped but has a two-humped pattern with highs at 09:00 a.m. and 03:00 p.m. This two-humped pattern is also found by Kleidon and Werner (1993). It is worth noting that the market was open between 08.30 and 16.30 GMT for the periods of these studies. Ellul et al. (2002) find a similar, but not identical, pattern for SETS and non-SETS stocks. They note that volumes for both categories of stock have a mid morning peak and then go relatively quiet until the US markets open at 2.30 p.m. GMT. Volumes then build until a peak at the end of the trading day at 4.30 p.m.

(iii) Intra Day Volatility

Return volatility can be seen as a direct measure of risk and an indirect measure of the level of information (French and Roll, 1986). Wood, McInish and Ord (1985), Jain and Joh (1988), McInish and Wood (1990), Lockwood and Linn (1990), in papers dealing with the NYSE, found a U-shaped pattern for volatility. Abhyankar, et al. (1997) found a similar U-shaped pattern for volatility in the LSE. Similarly, Madhavan, Richardson and Roomans (1997) showed that the variance of transaction price changes for NYSE stocks is U-shaped. They, however, found the variance of ask price changes to decline

across the day. More recently, Wang, Guan and Chang (1999) used Markov chains to study the intra day dynamics of the Nikkei index futures and found higher volatilities at market opening and closing. However, Andersen, Bollerslev and Cai (2000), examining the 5-min Nikkei 225 index returns from 1994 through to 1997, found that intra day volatility exhibits a doubly U-shaped pattern associated with the opening and closing of the separate morning and afternoon trading sessions.

3. INSTITUTIONAL BACKGROUND

In response to increasing competition, the LSE introduced an electronic order-matching system, SETS, in October 1997. The launch of SETS represented an important switch from quote driven to order driven market structures in London. The new order-driven system replaced SEAQ for all the FTSE100 stocks and will gradually be implemented for the FTSE250 stocks. Under this trading system, the LSE removed the obligation of dealers to quote firm two-way prices for FTSE 100 index stocks, and allowed the public to compete directly with dealers in these stocks through the submission of limit orders. The trading day for SETS securities runs from 08.00 hours to 16.30 hours on each Stock Exchange business day, subject to a random opening and closing time adjustment. The opening of the market is preceded by an opening auction period during which member firms are permitted to enter and delete limit orders and market orders on the order book. No order execution takes place during this period so it is possible that the order book will become crossed. At the end of the random start period (a random time between 08.00 and 08.30 hours), the order book is frozen temporarily and an auction-matching algorithm is run. No additional orders may be added or deleted until the auction matching process is complete for a given security. The trading day ends with a similar pre 16.30 closing auction period. Auctions may also take place during the trading day triggered by substantial price movements in a security.

SEAQ is a multi market maker electronic screen-based trading system. Market makers are obliged to quote two-way prices, during the MQP, for the stocks in which they are registered to

deal. Outside the MQP, market makers are not obliged to quote but may do so. However, prices are regarded as being indicative only.

At first glance it would be easy to conclude that some stocks (namely, the largest FTSE stocks) are traded via an order system (SETS) whilst others are traded through a dealer system (SEAQ). However, the ability of dealers still to quote for the largest stocks means that the distinction is not so clear-cut. This issue is well illustrated by Ellul et al.:

> Vodafone has the highest usage of the call auction and the call auction is used on nearly 50 percent of the sample period. However for all the other stocks, usage of the call auction is much more limited. British Telecom is ranked second in the table in terms of call auction usage, but only uses the call auction on 38 per cent of the sample period. In contrast British Telecom uses the dealership in 68 per cent of the sample over the opening period. Most of the remaining stocks have a similar bias towards the dealership rather than the call auction at the open (2002, p. 17).

In other words, while SETS stocks have the potential to be traded via an order book system, much of the liquidity for such stocks may well be provided by the dealership system.

For order book securities, members can still act as a counterparty for all order sizes and can conduct trades by phone, outside the central limit order book. Particularly large trades or trades with non-standard conditions can be negotiated away from the order book, enabling firms which commit risk capital to large trades to continue to do so. During 1998, the order book captured an average of 46% of trading by value (LSE, 1999). Approximately 85% of business in the order book securities, by value, was less than 8NMS[5] in 1998. The order book share of trades in excess of 8NMS is relatively low, with orders of this size generally being broken up into smaller NMS sizes before being worked through the book (LSE, 1999 4 M N PSO u).

It should be noted that since only the largest and most liquid stocks can be traded on SETS there is a difference between these stocks and stocks which are not traded on SETS. It is, therefore, necessary to be cautious about attributing different attributes of the intra day patterns observed to the trading system used as opposed to the properties of the stocks involved. This issue is considered further in Section 6 below.

4. DATA AND METHODOLOGY

(i) Data

The data are from the ICV MarketEye service and consist of time-stamped intra day best bid and ask price, transaction price and volume, and the stock status flag. The analysis covers the period from March to May 2001.[6] The data is derived at one-minute intervals for the range of variables described below and a total of 25 million observations inform the current analysis. However, the one-minute data are 'averaged' into 15-minute observations for the following reasons. First, the size of the interval allows the creation of a manageable and easily interpreted number of intra day dummy variables. Second, the creation of 15-minute interval data permits comparison of the current results with prior results (for example, Kleidon and Werner, 1993; and Abhyankar et al., 1997). However, it needs to be stressed that that current analysis is based on one-minute data that are averaged to give 15-minute observations and this is different from the usual practice of taking data observations at 15-minute time intervals. The practice of the current paper ensures that there is a higher information content to the data but that analysis and computation are still both practicable. In terms of this latter point, it should be noted that the sample consists of 822 stocks trading on the LSE in this period and contains both highly frequently traded and infrequently traded stocks. This sample of 822 stocks was chosen to allow close comparison with the Abhyankar et al. (1997) study of the UK market. While there has been more recent studies (Naik and Yadav, 2000; Taylor et al., 2000; Ellul, 2001; and Ellul et al., 2002) on specific aspects of the micro structure of UK stocks, the current research most closely mirrors that of Abhyankar et al. Both studies include approximately the same number (822 companies in the current study as compared to 835 companies in Abhyankar et al.) and types of companies, and cover the same broad research issues. All securities traded on SETS, 151 securities, are included in this analysis with 671 companies from the non-SETS trading system. Overall, therefore, a balance has been struck between the information content of the micro data, the formulation of variables, and the breadth of the sample and computability.

The daily time span for the data is the normal trading hours from 0800 to 1630. The current data set is different from Abhyankar et al. (1997) in that it does not include the pre-MQP and post-MQP for two reasons. First, the activities during the normal trading hours and pre or post normal trading hours are not comparable because the activity levels are different.[7] As mentioned in Section 3, quotes posted pre and post MQP are indicative only. Therefore, the inside bid-ask spreads calculated using these quotes are not comparable with those in the MQP. Second, to ensure comparability with the SETS data set, only the patterns of trading activity during the normal trading hours are examined.

Variables include return volatility (absR), volume measured as market turnover (MT), bid-ask spread (BAS), number of trades (NT) and trade size (TS). They are defined as follows.

Return Volatility (absR) – in terms of returns, 1-minute logarithmic returns are summed to construct 15-minute returns. The 1-minute returns are calculated based on the mid-quote prices rather than transaction prices to avoid any measurement errors due to bid-ask bounce. Following Abhyankar et al. (1997), absolute returns are used as the volatility measure.

Volume (MT) – in calculating a volume measure, this study uses market turnover (the ratio of the value of shares traded to market capitalisation) as the measure of volume rather than the unadjusted market value of shares traded. The main purpose of using market turnover is to set up a pooled regression with the companies being equally weighted so that the results are not biased towards the companies with the largest market value. Using market turnover has a secondary benefit of reducing heteroscedasticity. The 15-minute market volume is computed by summing market volume for each transaction during the 15 minutes.

Bid-Ask Spread (BAS) – the proportional spread rather than the absolute spread is used in estimating the bid-ask spread:

$$\mathrm{BAS}_t = \frac{\mathrm{Ask}_t - \mathrm{Bid}_t}{\mathrm{Mid}_t} \times 100.$$

For equities on the Market-Eye data service, the bid price is the best bid (the highest price being quoted) and the ask

price is the best offer (the lowest price being quoted). MID represents the mid-quote price between the current best bid price and the best ask price at period t. In the calculation, t is equal to the 1-minute interval. The 15-minute percentage bid-ask spread is computed by averaging the 1-minute spreads in the 15-minute period.

The differences in the bid-ask spread between stocks may cause a potential bias problem. Therefore, following the procedure in Abhyankar et al. (1997) and Levin and Wright (1999) amongst others, the proportional bid-ask spreads are standardised by dividing them by the mean of the series for that day.[8]

The number of trades (NT) is the number of trades in a 15-minute interval. Trade size (TS) is the average trade size which is the average market turnover for trades during a 15-minute period.

(ii) Methodology

Plots are used to show the intra day patterns. The statistical significance of the various patterns is tested by running the following regressions using Generalized Method of Moments estimation (GMM):

$$V_{i,t} = \sum_{i=1}^{16} a_i D_i + a_0 + \sum_{j=18}^{35} a_j D_j + e_{i,t}. \quad (1)$$

Where $D_i = 1$ if the observation lies in the ith quarter hour of the trading day (QOD); in total there are 35 QODs. The GMM estimates are computed using dummy variables for each 15 minutes except for the 17th (12:00–12:14) quarter hour of the trading day. The coefficient estimated a_0 is for the 17th quarter hour of the day, while the rest of coefficients a_1–a_{16} and a_{18}–a_{35} are the coefficients of quarter hour i relative to the 17th quarter hour of the day.[9] All standard errors are corrected simultaneously for autocorrelation and heteroscedasticity by using Hansen's (1982) GMM method and Newey and West's (1987) correction for serial correlation up to 12 lags. The significant values of the coefficients suggest the significance of the intra day patterns.

5. EMPIRICAL RESULTS

(i) Intra Day Bid-Ask Spread

In Figure 1a., the bid-ask spread has a reverse J-shaped pattern which is consistent with the findings of McInish and Wood (1992) and Kleidon and Werner (1993). The spread opens wide and narrows down in the first two trading hours and is relatively stable for the rest of the trading day. This result seems to contrast with the finding of Abhyankar et al. (1997) who show a U-shaped pattern of spread for the UK market but this seems to be largely created by the spread in the pre and post MQP.[10]

The results of the GMM estimation in Table 1 confirm the validity of the reserve J shape in that the coefficients of the dummy variables decrease and are significant for most of the day. Furthermore, the null hypothesis that the spread is constant across the day is rejected by the chi-square test shown at the foot of Table 1.

Breaking down the whole sample into the two sub samples of SETS (see Figure 1b. and Table 1b.) and non-SETS securities (see Figure 1c. and Table 1c.) indicates it is the SETS securities which are driving the overall inverted J shape pattern. The results for the SETS stocks support those of Naik and Yadav (2000) who also found sharply declining spreads at the start of the trading day. However, whereas Naik and Yadav (2000) found no significant intra-day variation in the spreads for non-SETS stocks, the results presented in Table 1 show a statistically significant decline in spreads for non-SETS stocks across the trading day. A similar result is noted by Ellul et al.:

> This narrowing of spreads throughout the day is a feature of both SETS and dealership systems, and is consistent with the increase in trading volumes illustrated in figure 1 (2002, p 19).

(ii) Intra Day Volume

The pattern of volume shown in Figure 2a. (namely, two peaks during the day – one between 10am to 11am and at 3.00pm with a further rally at the close of trading) is similar to that noted by Abhyankar et al. (1997) and Ellul et al. (2002). Furthermore, the clear inverse relationship between spreads

Figure 1
Intra Day Bid-Ask Spread

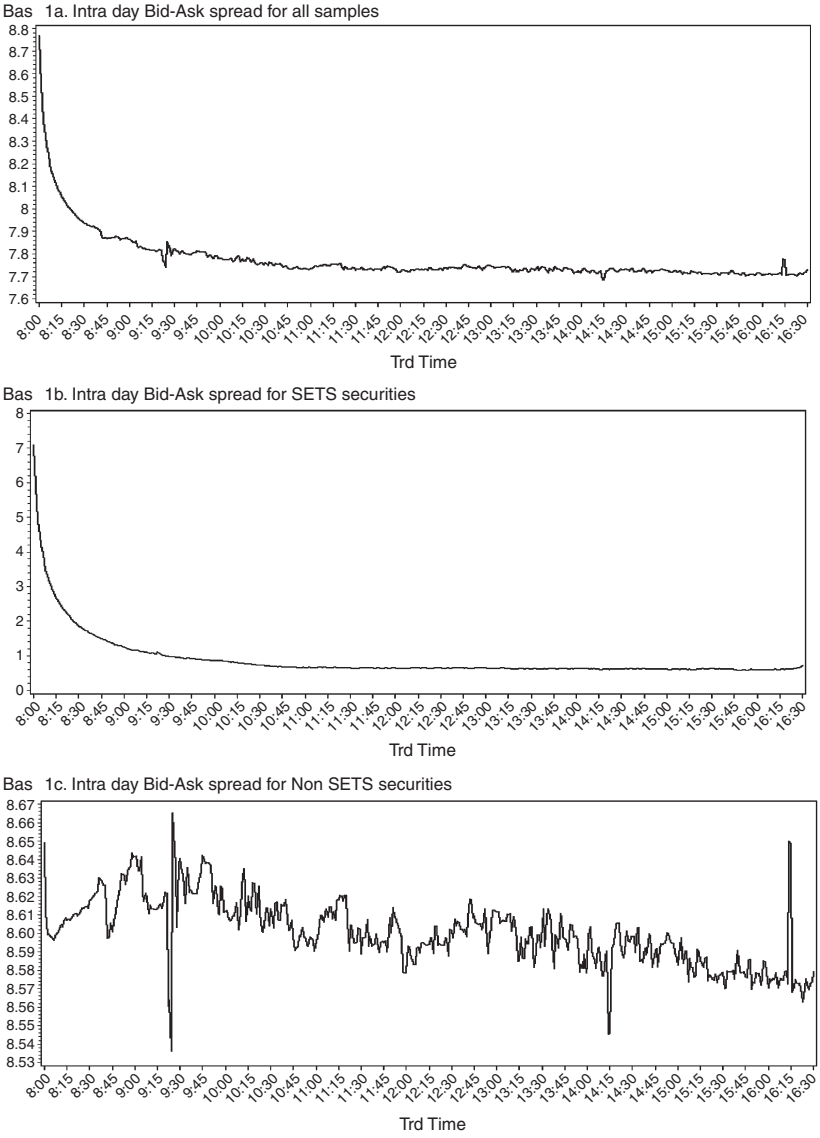


Table 1

Results of GMM Estimation of the Intra Day Bid-Ask Spread

	1a. All Samples (822 Securities)		*1b. SETS (151 Companies)*		*1c. Non-SETS (671 Companies)*	
	Estimate	*t-Value*	*Estimate*	*t-Value*	*Estimate*	*t-Value*
a1	1.7703	83.50***	5.3571	130.49***	1.0032	4.37***
a2	1.2963	85.27***	2.6329	123.46***	1.0066	7.68***
a3	1.1646	81.20***	1.8829	106.87***	1.0085	9.71***
a4	1.0957	67.30***	1.4911	78.00***	1.0097	11.10***
a5	1.0513	56.94***	1.2446	63.46***	1.0093	11.09***
a6	1.0311	41.62***	1.1376	43.26***	1.0079	9.86***
a7	1.0105	38.77***	1.0307	42.35***	1.0061	8.49***
a8	0.9972	31.69***	0.9623	34.55***	1.0049	7.36***
a9	0.9862	24.83***	0.9081	26.95***	1.0033	5.79***
a10	0.9699	14.54***	0.8229	15.28***	1.0020	4.57***
a11	0.9596	7.37***	0.7686	6.83***	1.0012	3.80***
a12	0.9547	3.77***	0.7424	2.36***	1.0010	3.72***
a13	0.9540	3.28***	0.7409	2.09**	1.0005	3.25***
a14	0.9526	2.28**	0.7369	1.43	0.9996	2.32**
a15	0.9494	−0.41	0.7229	−1.16	0.9989	1.46
a16	0.9481	−2.10**	0.7164	−3.03***	0.9987	1.60
a17	0.9499	947.35***	0.7289	170.75***	0.9981	1784.02***
a18	0.9491	−0.91	0.7254	−0.84	0.9979	−0.55
a19	0.9466	−3.16***	0.7120	−3.38***	0.9977	−0.64
a20	0.9482	−1.49	0.7221	−1.28	0.9975	−0.91

Table 1 (Continued)

	1a. All Samples (822 Securities)		*1b. SETS (151 Companies)*		*1c. Non-SETS (671 Companies)*	
	Estimate	*t-Value*	*Estimate*	*t-Value*	*Estimate*	*t-Value*
a21	0.9460	−3.25***	0.7089	−3.63***	0.9976	−0.62
a22	0.9431	−5.36***	0.6935	−6.21***	0.9975	−0.78
a23	0.9448	−3.94***	0.7038	−4.43***	0.9974	−0.92
a24	0.9458	−3.10***	0.7106	−3.20***	0.9970	−1.29
a25	0.9454	−3.30***	0.7088	−3.52***	0.9971	−1.20
a26	0.9436	−4.55***	0.6997	−4.99***	0.9968	−1.52
a27	0.9446	−3.81***	0.7102	−3.24***	0.9957	−2.72***
a28	0.9419	−5.60***	0.6969	−5.48***	0.9954	−3.08***
a29	0.9406	−6.35***	0.6912	−6.40***	0.9951	−3.36***
a30	0.9428	−4.87***	0.7025	−4.49***	0.9952	−3.12***
a31	0.9447	−3.52***	0.7083	−3.51***	0.9963	−1.87*
a32	0.9358	−9.20***	0.6581	−11.79***	0.9964	−1.68*
a33	0.9396	−6.78***	0.6772	−8.74***	0.9968	−1.23
a34	0.9431	−4.46***	0.6949	−5.72***	0.9972	−0.83
a35	0.9679	9.76***	0.8290	11.60***	0.9976	−0.47
Chi-Square		12863***		37350***		246.91***

Notes:
*** Indicates significant at the 1% level.
** Indicates significant at the 5% level.
* Indicates significant at the 10% level.
The Chi-Square statistic is testing whether the coefficients for the dummy variables are jointly zero.
The level of a_i is recovered by the following equation: $a_0 + a_i$ and $a_{17} = a_0$.

and volume, which can be seen by comparing Figure 1a. and Figure 2a., is consistent with Kleidon and Werner's (1993) finding when they cut off the periods outside the MQP. Similarly, Ellul et al. (2002) note declining spreads and increased volumes across the trading day. The types of spread model developed by Glosten and Milgrom (1985) and Kyle (1985) may help to explain the inverse relationship between spreads and volumes. These models are based on dynamic models of insider trading within a sequential auction market. Glosten and Milgrom (1985), in particular, show that an inverse relationship between spread and volume is to be expected. They state that 'Loosely speaking, markets in which there is, on average, large volume will have small average spreads and vice versa' (p. 87).

The volume pattern of SETS (see Figure 2b.) is different from that of non-SETS (see Figure 2c.) in that it has a peak at about 3:00pm. One explanation of this is that the SETS securities are more international in terms of their trading and more specifically, the US market opens at 2:30pm GMT and this impacts positively on the trading volume of SETS securities for 30 minutes after the open of the US market. Whilst the impact is not so dramatic, the volume of non-Sets securities also starts to increase at about 2:30pm.

Further analyses on the components of volume; that is, the number of trades (see Figure 2d.) and trade size (see Figure 2e.), reveal that both of them contribute to the volume pattern. This is in contrast to Abhyankar et al. (1997) who find that the trading size (average of volume of stocks traded per transactions) is fairly constant through the day. However, their pattern for trade size is seriously affected by the high trade size after MQP and if these observations are removed, then the pattern is similar to the one noted here.

The GMM estimation in Table 2 confirms the pattern observed in the plots with the variable changing cyclically to reveal two peaks in the pattern. The twin peak result noted here and by Kleidon and Werner (1993) and Abhyankar et al. (1997) for the UK contrasts with the U-shaped pattern found in most of the US studies (see, for example, Wood, McInish and Ord, 1985; and Gerety and Mulherin, 1992). Abhyankar et al. (1997) explored this by looking at the volume pattern of stocks in the highest and lowest deciles by trading volume. They found that a U-shaped

pattern is more visible in heavily traded stocks, while thinly traded stocks have a two-humped structure. They concluded that:

> it is possible that the differential trading patterns among stocks of different liquidities produces the two-humped structure in the aggregate sample . . . (p. 355).

Figure 2
Intra Day Volume

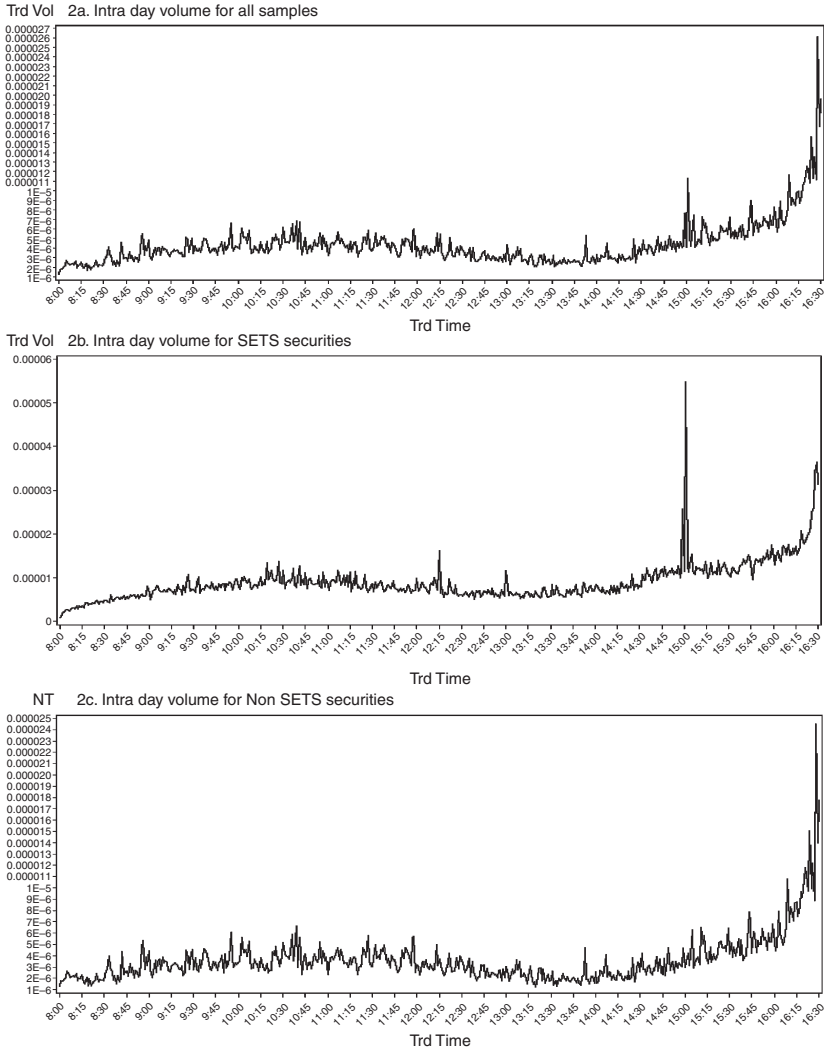
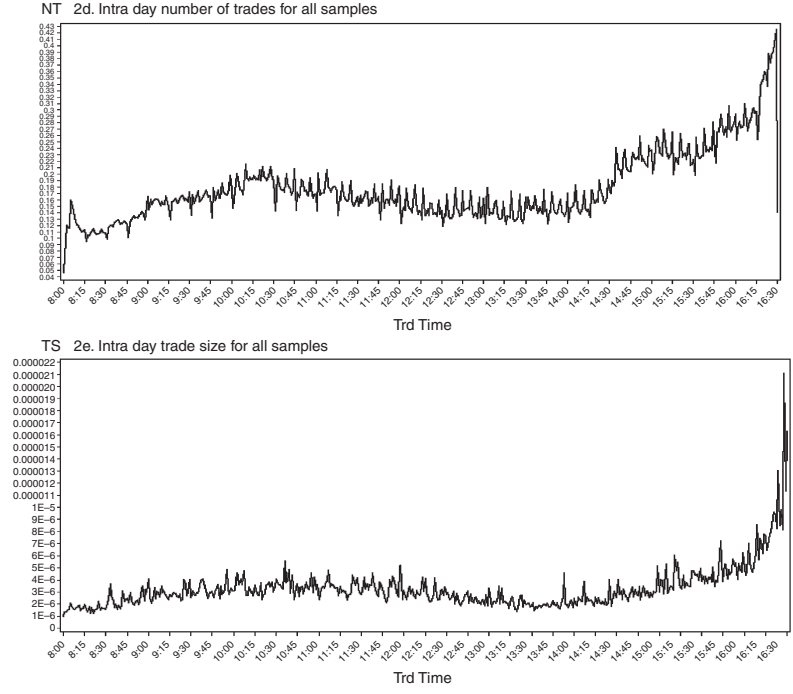


Figure 2 (Continued)



However, the GMM estimates for SETS and non-SETS in Table 2 indicate that trading volumes for these subsets have a pattern similar to that of the overall sample. This result suggests that the differences in the volume pattern between the UK and the US may be a reflection of institutional factors rather than differences between thinly and heavy traded securities. One possible explanation is that in the US it is not possible to trade overnight. In contrast, nearly 3% of the trades of SETS securities in value and 0.8% of SEAQ securities are overnight trades, and this may be an explanation of why demand is not relatively large at the opening of the LSE market.

(iii) Intra Day Volatility

From both Figure 3 and the GMM estimates (see Table 3) it is clear that the pattern of volatility is U-shaped in that the coeffi-

Table 2

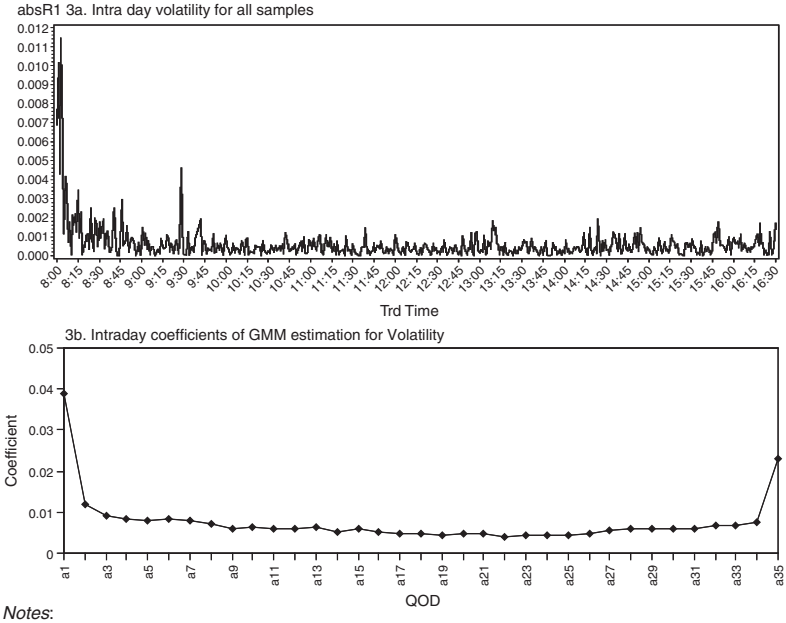
Results of GMM Estimation of the Intra Day Volume

	2a. All Samples (822 Securities)		*2b. SETS (151 Companies)*		*2c. Non-SETS (671 Companies)*	
	Estimate	*t-Value*	*Estimate*	*t-Value*	*Estimate*	*t-Value*
a1	2.15E-06	−10.66***	2.91E-06	−12.01***	1.98E-06	−5.55***
a2	2.25E-06	−9.80***	4.27E-06	−8.86***	1.82E-06	−6.35***
a3	2.93E-06	−4.43***	5.27E-06	−6.66***	2.42E-06	−2.16***
a4	3.49E-06	−1.16	6.09E-06	−4.69***	2.92E-06	−0.07
a5	3.81E-06	−0.41	7.16E-06	−2.27**	3.08E-06	0.60
a6	4.13E-06	1.04	7.68E-06	−1.04	3.35E-06	1.57
a7	4.03E-06	0.60	7.80E-06	−0.74	3.21E-06	1.01
a8	4.60E-06	2.14**	8.55E-06	0.74	3.74E-06	2.02**
a9	4.62E-06	3.41***	8.90E-06	1.26	3.69E-06	3.19***
a10	4.59E-06	2.75***	1.02E-05	2.99***	3.36E-06	1.51
a11	4.95E-06	3.66***	9.72E-06	2.84***	3.91E-06	2.88***
a12	4.59E-06	3.09***	9.34E-06	2.32**	3.56E-06	2.38**
a13	4.54E-06	3.41***	9.42E-06	2.51**	3.48E-06	2.55**
a14	4.55E-06	2.45**	8.52E-06	0.64	3.68E-06	2.37**
a15	4.55E-06	2.40**	8.09E-06	−0.25	3.78E-06	2.58***
a16	4.13E-06	0.93	7.28E-06	−2.11**	3.44E-06	1.66*
a17	3.89E-06	25.92***	8.20E-06	20.37***	2.95E-06	18.44***
a18	3.88E-06	−0.02	7.68E-06	−1.03	3.06E-06	0.40
a19	3.35E-06	−2.64***	6.26E-06	−4.44***	2.71E-06	−1.03
a20	3.09E-06	−4.13***	6.41E-06	−3.91***	2.37E-06	−2.73***
a21	3.23E-06	−2.84***	6.74E-06	−2.91***	2.46E-06	−1.86*
a22	2.88E-06	−4.29***	6.44E-06	−3.27***	2.11E-06	−3.23***

a23	2.72E-06	−6.45***	6.56E-06	−3.73***	1.88E-06	−5.37***
a24	2.92E-06	−5.36***	7.24E-06	−2.04**	1.98E-06	−4.99***
a25	3.15E-06	−3.49***	7.58E-06	−1.14	2.19E-06	−3.35***
a26	3.48E-06	−1.86*	8.17E-06	−0.06	2.45E-06	−2.00**
a27	4.33E-06	1.80*	1.04E-05	4.03***	3.00E-06	0.19
a28	4.95E-06	4.71***	1.26E-05	8.29***	3.28E-06	1.34
a29	6.13E-06	3.64***	1.54E-05	2.41**	4.12E-06	3.09***
a30	5.67E-06	6.43***	1.21E-05	7.93***	4.27E-06	4.13***
a31	6.16E-06	7.39***	1.29E-05	8.43***	4.69E-06	4.93***
a32	7.04E-06	10.58***	1.45E-05	11.71***	5.41E-06	7.20***
a33	8.19E-06	12.70***	1.58E-05	13.40***	6.52E-06	9.09***
a34	1.30E-05	26.08***	2.22E-05	22.26***	1.10E-05	20.03***
a35	2.09E-05	2.74***	3.22E-05	6.87***	1.80E-05	2.07**
Chi-Square		2447.90***		2811.90***		1201.70***

Notes:
*** Indicates significant at the 1% level.
** Indicates significant at the 5% level.
* Indicates significant at the 10% level.
The Chi-Square statistic is testing whether the coefficients for the dummy variables are jointly zero.
The level of a_i is recovered by the following equation: $a_0 + a_i$ and $a_{17} = a_0$.

Figure 3
Intra Day Volatility



Notes:
The coefficients are from Table 3. The level of a_i is recovered by the following equation: $a_0 + a_i$ and $a_i = a_0$.

cients are high at market open, decrease over the day and rise towards the end of the trading day. This result is similar to that of Abhyankar et al. (1997) and Kleidon and Werner (1993). Breaking down the sample into SETS and non-SETS subsets gives the same result.

This finding for volatility is not consistent with Admati and Pfleiderer (1988) who predict the variability of price changes to be higher in periods of concentrated trading because more information is revealed in this period by actions of informed traders. However, this finding, together with the pattern of spread and volume (see Figure 2a.), is consistent with Foster and Viswanathan's (1990) prediction that low bid-ask spreads and low volatility exist in the period when volume is higher. This suggests that in the London market investors prefer not to trade (low trading volumes) at the market opening because

Table 3

Results of GMM Estimation of the Intra Day Volatility

	3a. All Samples (822 Securities)		*3b. SETS (151 Companies)*		*3c. Non-SETS (671 Companies)*	
	Estimate	*t-Value*	*Estimate*	*t-Value*	*Estimate*	*t-Value*
a1	0.0389	47.25***	0.1016	29.31***	0.0255	39.09***
a2	0.0119	18.94***	0.0413	14.49***	0.0055	13.37***
a3	0.0091	19.20***	0.0285	18.92***	0.0048	10.81***
a4	0.0081	14.63***	0.0254	14.72***	0.0044	8.24***
a5	0.0081	14.52***	0.0249	13.17***	0.0044	8.75***
a6	0.0085	3.93***	0.0246	10.10***	0.0050	2.22***
a7	0.0081	12.06***	0.0253	9.93***	0.0044	7.57***
a8	0.0071	9.62***	0.0210	8.27***	0.0041	6.38***
a9	0.0061	7.03***	0.0208	9.39***	0.0030	2.44**
a10	0.0062	7.20***	0.0206	9.81***	0.0031	2.82***
a11	0.0061	7.73***	0.0214	10.67***	0.0028	1.93*
a12	0.0059	5.45***	0.0196	6.31***	0.0029	2.11**
a13	0.0063	6.32***	0.0189	4.72***	0.0035	4.42***
a14	0.0052	2.63***	0.0167	2.91***	0.0027	1.36
a15	0.0059	4.42***	0.0181	3.96***	0.0032	2.86***
a16	0.0051	1.74*	0.0160	1.55	0.0028	1.25
a17	0.0048	37.69***	0.0153	43.67***	0.0025	18.83***
a18	0.0048	−0.11	0.0151	−0.54	0.0025	0.18
a19	0.0044	−2.34**	0.0146	−1.70*	0.0022	−1.70*
a20	0.0049	0.88	0.0154	0.03	0.0027	1.02

Table 3 (Continued)

	3a. All Samples (822 Securities)		*3b. SETS (151 Companies)*		*3c. Non-SETS (671 Companies)*	
	Estimate	*t-Value*	*Estimate*	*t-Value*	*Estimate*	*t-Value*
a21	0.0046	−0.92	0.0140	−3.04***	0.0026	0.53
a22	0.0041	−3.94***	0.0141	−2.68***	0.0020	−3.00***
a23	0.0045	−1.97**	0.0163	2.07**	0.0019	−3.67***
a24	0.0044	−2.41**	0.0151	−0.51	0.0021	−2.50**
a25	0.0045	−1.94*	0.0156	0.57	0.0020	−2.57**
a26	0.0049	0.74	0.0167	2.76***	0.0023	−0.82
a27	0.0056	4.60***	0.0189	7.77***	0.0027	1.19
a28	0.0059	6.41***	0.0207	9.94***	0.0027	1.06
a29	0.0060	7.07***	0.0205	11.07***	0.0029	2.26**
a30	0.0061	7.82***	0.0207	10.26***	0.0029	2.78***
a31	0.0061	7.49***	0.0211	10.91***	0.0028	2.03**
a32	0.0068	10.90***	0.0236	15.37***	0.0032	3.62***
a33	0.0067	10.91***	0.0240	15.72***	0.0030	2.84***
a34	0.0073	14.13***	0.0286	22.46***	0.0027	1.39
a35	0.0231	29.40***	0.1167	40.78***	0.0031	1.30
Chi-Square		3677.60***		3579.40***		1916.10***

Notes:
*** Indicates significant at the 1% level.
** Indicates significant at the 5% level.
* Indicates significant at the 10% level.
The Chi-Square statistic is testing whether the coefficients for the dummy variables are jointly zero.
The level of a_i is recovered by the following equation: $a_0 + a_i$ and $a_{17} = a_0$.

there is higher risk (high volatility) and larger trading costs (high spread). Not surprisingly, volume increases after 10pm when both risk and cost decrease.

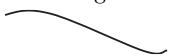
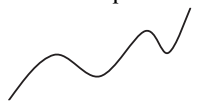
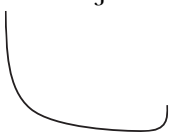
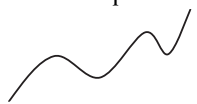
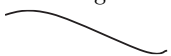
6. DISCUSSION AND CONCLUSIONS

Given the varied objectives of this paper, Table 4 summarises, at a general level, prior and current results. One of the most striking observations to be drawn from Table 4 is that volatility (column 5) tends to be U-shaped in both the UK and US markets, across different time periods for the UK and across different trading systems in the US and the UK. Furthermore, a similar result has been noted for the developed markets in the Far East (Singapore: Ding and Lau, 2001; Japan: though Anderson, Bollerslev and Cai, 2000, found a double u shape). In addition, Taylor et al. (2000) found that the introduction of SETS had no significant impact, *ceteris paribus*, on the average volatility of the market. Therefore, different institutional frameworks and trading systems do not seem to impact on the shape or level of the volatility of returns in developed trading markets and this raises the question whether the result holds in the less developed markets.

Whilst not as striking, the results for volume (column 4) are equally interesting. The results for the two US markets (and their different trading systems) give the same U-shaped pattern and one explanation of this phenomenon is the general absence of overnight trades in the US.[11] In contrast, the general pattern for the UK is two humped. The ability to trade overnight may well explain the absence of large volumes at market opening, the volumes increasing to a mid morning high as the costs of trading (the spread) declines. The mid-day lull can be explained by the need to have lunch and the hump in the middle of the afternoon (building to a peak at 3.00pm) can be explained by the opening of the US markets. Not surprisingly, the less international non-SETS stocks do not display such an obvious international effect. Both SETS and non-SETS stocks show increasing volumes as the market moves towards closing, and a similar pattern is noted in Ellul et al. (2002). In summary, the differences between the US and the UK can be characterised as

Table 4

Summary of Results Across Markets

1. Markets	*2. Trading System*	*3. BAS*	*4. Volume*	*5. Volatility*
NYSE	Specialist market	U-shaped 	U-shaped 	U-shaped 
NASDAQ	Multi-dealer market	Stable but declining in final hour 	U-shaped 	U-shaped 
Previous works on LSE	Multi-dealer market	Declining[12] 	Two-humped 	U-shaped 
SETS	Order-driven (limit order) market	Reverse J 	Two-humped 	U-shaped 
Non SETS	Multi-dealer market	Declining 	Two-peaks 	U-shaped 

the ability to trade overnight in the UK and the impact of the opening of the US markets on major stocks in the UK. Interestingly, the different trading systems in the UK have seemingly little general impact on the pattern of volume.

In terms of spreads (column 3), it is apparent that in multi-dealer markets, spreads decline across the whole day, whereas for the specialist market of the NYSE and the order driven market of SETS, spreads decline quickly in the opening hours of the market and then remain stable for the rest of the trading day, apart from a small increase towards the close of the market. In theory, from this analysis in isolation, it is not possible to be certain whether the different patterns of spreads observed, in the UK, for SETS stocks compared to non-SETS stocks are due to the properties of the stocks traded on SETS or to the nature of the SETS trading system. The paper of Naik and Yadav (2000) sheds further light on this issue. The authors compare the spreads of stocks quoted on the LSE before and after the introduction of SETS and note that the spreads at market open have substantially increased for stocks traded on SETS. This finding tends to indicate that some of the observed differences between the spreads of SETS and non-SETS stocks may be caused by the properties of the different trading systems. In general, the findings of Naik and Yadav regarding spreads are similar to those reported here with sizeable spreads at market open followed by rapid decreases across the first hour of trading for stocks traded on SETS. Another issue is that, as noted in the main body of the text, the SETS stocks are traded both through the order and dealership systems, and the latter may, indeed, be providing a lot of the liquidity. Naik and Yadav (2000) and Ellul et al. (2002) both conclude that the dealership system may well provide a useful source complementary liquidity at market open.

The primary theoretical explanations of the shape of the above intra day variables are information models (see, for example, Kyle, 1985; Glosten and Milgrom; 1985, Admati and Pfleiderer, 1988; and Foster and Viswanathan, 1990) and market closure models (see, for example, Brock and Kleidon, 1992). Information models predict that greater information asymmetry between informed traders and uninformed liquidity providers leads to wider spreads as uninformed liquidity traders

attempt to minimise losses from informed trading. Admati and Pfleiderer (1988) predict in equilibrium, low bid-ask spreads and high volatility are associated with the period when volume is higher. However, Foster and Viswanathan (1990) predict low bid-ask spreads and low volatility in periods when volume is higher. Market closure models examine the implications of periodic closure on the dynamics of volume and the bid-ask spreads. Brock and Kleidon (1992) suggest that liquidity demand is more inelastic at the open and close of the market than the rest of the day. More specifically, the market makers or specialists will be able to charge a larger spread at market open and close by exploiting these differentials in liquidity demand elasticity when many traders will prefer to close their position without carrying overnight risk. Thus, the model predicts a U-shaped pattern in both intra day volume and spread, which is consistent with the evidence for the NYSE. None of the above models is, however, able to explain the intra day patterns of *all* three variables in either the US or UK markets. Furthermore, as these models have been developed to explain the pattern of spreads in quote driven markets, there is an obvious need to consider if new theoretical explanations are needed for order driven markets.

In conclusion, with the benefit of very high frequency and recent data for the UK, this paper has had a range of objectives. First, in terms of measuring and documenting a range of stock market characteristics, the paper has documented significant intra day variations in volatility, spreads and volumes irrespective of whether stocks are traded on the SETS or non-SETS trading systems. The results indicate a U-shaped pattern of volatility (a common finding for all markets irrespective of the differences in their institutional settings), a distinct reserve J shaped pattern of spreads for the SETS securities (confirming the results of Naik and Yadav, 2000), a declining spread pattern for the non-SETS securities (confirming the results of Ellul et al., 2002) and a two-hump volume pattern (confirming the results of Abhyankar et al., 1997; Kleidon and Werner, 1993; and Ellul et al., 2002). Second, in terms of complementing the mainly US based literature, the paper has compared and contrasted its findings with studies on NYSE and NASDAQ. It shows that the differences of trading systems (i.e. specialists quote-driven,

multi-dealer quote-driven, and order-driven systems) affect the bid-ask spread patterns while the differences of market environments (i.e. US and UK markets) affect the volume pattern. Though it has to be accepted that results for order driven and dealership systems may not be as clear cut as might be hoped because stocks being handled by the order system may also be traded via the dealership system. In the context of the UK, SETS stocks can be traded via both the order and dealership systems. Allowing for this last comment, the final objective of the current paper has been to explore the differences between the order driven SETS system and the quote driven non-SETS system. The paper has noted that except for the bid ask spread, the intraday variables of SETS and non-SETS stocks show the same pattern. This suggests that the main differences across the different trading systems, accepting there are interference effects between the two systems, are primarily a function of trading costs and price discovery processes.

From the basis of the above there are two obvious directions for further work. First, while most of the prior theoretical studies attribute the observed intra day variations of market variables to the behaviour of specialists or market makers, the results presented here for the SETS stocks suggest that this cannot be the sole explanation as the SETS system is not based primarily on market-makers. Further theoretical research will be needed to consider what factors are significant in determining intra-day patterns for different trading systems (i.e. quote driven and order driven systems), operating both independently and interdependently. Second, additional cross-market comparisons will help to identify how institutional factors affect the behaviour of investors on an intra day basis.

NOTES

1 The experiment was performed by Eadweard Muybridge of the University of Pennsylvania in the mid 1880s as reported in 'Photography as a Tool', *Life Library of Photography* (1972, pp. 14–15).

2 The time period when market makers on SEAQ and SEAQ International are obliged to make firm two-way quotes for the securities in which they are registered is now from 08.00 to 16.30 (GMT), while it was from 08.30 to 16.30 (GMT) in previous studies (Kleidon and Werner, 1993; and Abhyankar et al., 1997). The equivalent periods for the NYSE and NASDAQ are from 14.30 to 21.00 (GMT).

3 Chan et al. (1995) argue that in the multi-dealer system, individual dealers will not be able to exploit the high opening demand by increasing the spread as the specialists do. They explain the decline of spread as a price discovery process and attribute the narrowing of the spread at closing to the improved quotes from dealers who need to balance their inventory. It should be noted, however, that the NASDAQ changed in 1997 to a system that incorporated features of an order driven system.
4 In investigating the effects of market reform Naik and Yadav also note a number of other effects including the disappearance of cross-subsidisation across trade sizes, leading to a substantial decline in the average execution costs of small public trades but an increase for large public trades.
5 The NMS (Normal Market Size) which is determined by the Exchange, is based on customer turnover in each stock over the previous twelve months expressed in a number of shares; this currently ranges from 500 to 200,000 shares.
6 An investigation period of three months contains enough information to carry out this analysis whilst still being manageable in terms of the data computation involved. In the three-month investigation period there are about 2,000 observations for each company when observations are computed at 15-minute intervals and about 30,000 observations for each company when observations are taken at 1-minute intervals. The analysis has also been conducted on the index series of SETS and non-SETS stocks for a one-year period from September 1998 to August 1999 with very similar results to those presented in this paper.
7 This can be demonstrated by examining the number of quotes posted which drops dramatically from about 275,000 at 16:30 to 10,000 at 16:45 and 0 after 17:00 (Figure 2, Abhyankar et al., 1997, p. 354). Trading volumes also drops from about 1.16 (times 10E9) at 16:30 to 0.06 (times 10E9) at 16:45 (Figure 3, Abhyankar et al., 1997, p. 354). A similar magnitude of change in trading volume occurs in the pre-opening period. Therefore, observations outside the MQP can be considered extreme compared to those within the MQP.
8 If the proportional bid-ask spreads are not standardised the results will be biased towards the companies with the largest bid-ask spreads. Standardisation has the effect of equally weighting the influence of the companies and also has the benefit of reducing heteroscedasticity.
9 For clarity of interpretation, in Tables 1–3 the results have been presented as 35 dummies (one for each quarter hour) with no constant term by using the transformations: $a_i = a_0 + a_i$ and $a_{17} = a_0$.
10 The MQP in Abhyankar et al. (1997) is from 08:30 to 16:30.
11 This is the basis of the market closure model for intra day patterns (see Brock and Kleidon, 1992).
12 If pre and post MQP trading is included, it will be U shaped because of the high spread outside of the MQP. In terms of the MQP, however, it mainly declines.

REFERENCES

Abhyankar, A., D. Ghosh, E. Levin and R.J. Limmack (1997), 'Bid-ask Spreads, Trading Volume and Volatility: Intra-day Evidence from the London Stock Exchange', *Journal of Business Finance & Accounting*, Vol. 24, pp. 343–62.

Admati, A. and P. Pfleiderer (1988), 'A Theory of Intra-day Patterns: Volume and Price Variability', *Review of Financial Studies*, Vol. 1, pp. 3–40.

Ahn, H.J and Y.L. Cheung (1999), 'The Intra-day Patterns of the Spread and Depth in a Market without Market Makers: The Stock Exchange of Hong Kong', *Pacific Basin Finance Journal*, Vol. 7, pp. 539–56.

Andersen, T.G., T. Bollerslev and J. Cai (2000), 'Intra-day and Interday Volatility in the Japanese Stock Market', *Journal of International Financial Markets, Institutions and Money*, Vol. 10, pp. 107–30.

Atkins, A.B. and S. Basu (1995), 'The Effect of After-Hours Announcements on the Intra-day U-Shaped Volume Pattern', *Journal of Business Finance & Accounting*, Vol. 22, pp. 789–809.

Brock, W.A. and A.W. Kleidon (1992), 'Periodic Market Closure and Trading Volume: A Model of Intra Day Bids and Asks', *Journal of Economic Dynamics and Control*, Vol. 16, pp. 451–89.

Chan, K.C., W.G. Christie and P.H. Schultz (1995), 'Market Structure and the Intra Day Pattern of Bid-Ask Spreads for Nasdaq Securities', *Journal of Business*, Vol. 68, pp. 35–60.

Cheung, Y.L. (1995), 'Intra Day Returns and the Day-End Effect: Evidence from the Hong Kong Equity Market', *Journal of Business Finance & Accounting*, Vol. 22, pp. 1023–34.

Ding, D.K. and S.T. Lau (2001), 'An Analysis of Transactions Data for the Stock Exchange of Singapore: Patterns, Absolute Price Change, Trade Size and Number of Transactions', *Journal of Business Finance & Accounting*, Vol. 28, pp. 151–72.

Ellul, A. (2001), 'The Dealers Ride Again: Volatility and Order Flow Dynamics in a Hybrid Market', Working Paper (London School of Economics, Financial Markets Group).

———, H.S. Shin and I. Tonks (2002), 'Toward Deep and Liquid Markets: Lessons from the Open and Close at the London Stock Exchange', Working Paper (London School of Economics, Financial Markets Group).

Foster, F. and S. Viswanathan (1990), 'A Theory of the Interday Variations in Volume, Variance, and Trading Costs in Securities Markets', *Review of Financial Studies*, Vol. 3, pp. 593–624.

French, K.R and R. Roll (1986), 'Stock Return Variances: The Arrival of Information and the Reactions of Traders', *Journal of Financial Economics*, Vol. 17, pp. 5–26.

Gerety, M.S. and J.H. Mulherin (1992), 'Trading Halts and Market Activity: An Analysis of Volume at the Open and the Close', *Journal of Finance*, Vol. 5, pp. 1765–811.

Glosten, L.R. and P.R. Milgrom (1985), 'Bid, Ask and Transaction Prices in a Specialist Market with Heterogeneously Informed Traders', *Journal of Financial Economics*, Vol. 14, pp. 71–100.

Hamao, Y. and J. Hasbrouck (1995), 'Securities Trading in the Absence of Dealers: Trades and Quotes on the Tokyo Stock Exchange', *Review of Financial Studies*, Vol. 8, pp. 849–78.

Hansen, L. (1982), 'Large Sample Properties of Generalized Method of Moments Estimators', *Econometrica*, Vol. 50, pp. 1029–54.

Harris, L. (1986), 'A Transaction Data Study of Weekly and Intra Day Patterns in Stock Returns', *Journal of Financial Economics*, Vol. 16, pp. 99–118.

Ho, R. and Y.L. Cheung (1994), 'Seasonal Pattern in Volatility in Asian Stock Markets', *Journal of International Financial Markets, Institutions and Money*, Vol. 4, pp. 61–67.

Jain, P.C. and G.H. Joh (1988), 'The Dependence Between Hourly Prices and Trading Volume', *Journal of Financial and Quantitative Analysis*, Vol. 23, pp. 269–83.

Kleidon, A. and I. Werner (1993), 'Round-the-Clock Trading: Evidence from U.K. Cross-Listed Securities', Working Paper (National Bureau of Economic Research).

Kyle A.S. (1985), 'Continuous Auctions and Insider Trading', *Econometrica*, Vol. 53, Issue 6, pp. 1315–36.

Lee, C.M.C., B. Mucklow and M.J. Ready (1993), 'Spreads, Depths, and the Impact of Earnings Information: An Intra Day Analysis', *Review of Financial Studies*, Vol. 6, pp. 345–74.

Levin, E.J. and R.E. Wright (1999), 'Why Does the Bid-Ask Spread Vary Over the Day?', *Applied Economics Letters*, Vol. 6, pp. 563–67.

Lockwood, L.J. and S.C. Linn (1990), 'An Examination of Stock Market Return Volatility During Overnight and Intra-day Periods, 1964–1989', *Journal of Finance*, Vol. 45, pp. 591–601.

LSE (1999), 'Markets Analysis—Market Statistics from the London Stock Exchanges, 26 March 1999' (London Stock Exchange).

Madhavan, A., M. Richardson and M. Roomans (1997), 'Why Do Security Prices Change? A Transaction-Level Analysis of Nyse Stocks', *Review of Financial Studies*, Vol. 10, pp. 1035–64.

McInish, T.H. and R.A. Wood (1985), 'Intra-day and Overnight Returns and Day-of-the-Week Effects', *Journal of Financial Research*, Vol. 8, pp. 119–26.

——— ——— (1990), 'A Transactions Data Analysis of the Variability of Common Stock Returns During 1980–1984', *Journal of Banking and Finance*, Vol. 14, pp. 99–112.

——— ——— (1992), 'An Analysis of Intra-day Patterns in Bid/Ask Spreads for Nyse Stocks', *Journal of Finance*, Vol. 47, pp. 753–64.

Naik, N. Y. and P.K. Yadav (1999), 'The Effects of Market Reform on Trading Costs of Public Investors: Evidence from the London Stock Exchange', Working Paper (London Business School, Institute of Finance and Accounting).

Newey, W. and K. West (1987), 'A Simple Positive Semi-Definite, Heteroscedasticity and Autocorrelation Consitent Covariance Matrix', *Econometrica*, Vol. 55, pp. 703–8.

Short, H. and K. Keasey (1999), 'Managerial Ownership and the Performance of Firms: Evidence from the UK, *Journal of Corporate Finance*, Vol 5, pp. 79–101.

Taylor, N., D. van Dijk, P.H. Franses and A. Lucas (2000), 'SETS, Arbitrage Activity, and Stock Price Dynamics', *Journal of Banking and Finance*, Vol. 24, pp. 1289–306.

Wang, E., R. Hudson and K. Keasey (2000), 'Tick Size and the Compass Rose: Further Insights', *Economic Letters*, Vol. 68, pp. 119–25.

Wang, S., L.K. Guan and C. Chang (1999), 'A New Methodology for Studying Intra-day Dynamics of Nikkei Index Futures Using Markov Chains', *Journal of International Financial Markets, Institutions and Money*, Vol. 9, pp. 247–65.

Wood, R., T. McInish and J. Ord (1985), 'An Investigation of Transactions Data for NYSE Stocks', *Journal of Finance*, Vol. 40, pp. 723–39.

Yadav, P.K. and P.F. Pope (1992), 'Intraweek and Intra-day Seasonalities in Stock Market Risk Premia: Cash and Futures', *Journal of Banking and Finance*, Vol. 16, pp. 233–70.