After-hours Trading in Equity Futures Markets

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Abstract
While it is well known that electronic futures data absorb news (slightly) in advance of spot markets the role of the electronic futures movement in out of hours trading has not previously been explored. The behaviour of the 24 hour trade in the S&P 500 and Nasdaq 100 futures market reveals the important role of these markets in absorbing news releases occurring outside of normal trading hours. Peaks in volume and volatility in this market occur in conjunction with US 8:30am EST news releases, prior to the opening of the open-outcry markets, and in a less pronounced fashion immediately post-close the open-outcry market. Price impact in these markets is statistically higher in the post-close than pre-open periods.

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1. Introduction

Spot and futures equity markets generally have formal opening and closing times for floor based trade, but increasingly these markets can be accessed via electronic trading systems anywhere in the world, 24 hours a day, though not (so far at least) over the weekend break. One reason why this is important is that many researchers in this field have taken the temporal passage of the spot, or futures (for the same set of hours as the spot market) markets around the world as providing an indication of, or proxy for, causal relationships between markets. Thus, for example, the change in price between the open and close of the NYSE is used as an explanatory variable in equations to model the change in price between the previous close to the new open of the Tokyo Stock Exchange, or the London Stock Exchange (Engle et al., 1990).

While this process is not biased, it may distribute the effects of news incorrectly in 24 hour markets. For example, many economic news announcements in the US occur at 8:30am EST, before the opening of the NYSE, see also Andersen, Bollerslev, Diebold and Vega (2006) who for this reason use futures rather than spot market data. Company data are also often announced after the market has officially shut; in previous times this was at least partly to protect the companies from over reactions to data, allowing analysts time to absorb the information before responding with market actions on the next day. More recently the advent of extended hours trading on Electronic Communication Networks (ECNs) has increased the hours for spot trading in equity markets. In the presence of 24 hour trading electronic markets, the effects of news in equity markets should be incorporated immediately, just as in the foreign exchange markets; for an analysis of diurnal patterns in foreign exchange markets see Huang and Masulis (1999).

This paper shows the effects of after-hours trade on the absorption of news releases using GLOBEX data on S&P500 and NASDAQ 100 futures contracts traded on the Chicago Mercantile Exchange.

The electronic futures markets of the CME provide a particularly interesting set of circumstances for investigating the impact of market structure on price discovery. Three products essentially co-exist. The first is the standard futures pit-contract which trades in the physical pit during the regular trading hours of 8:30 am until 15:15 pm CST. The second is the corresponding electronic product of the same contract size which trades on the GLOBEX exchange during the non-pit trading hours. Both contracts can co-exist due to the different pricing structures which favour action during regular trading hours where possible. The third product is the newer E-minis which trade only electronically around the clock and whose size is around one-fifth of the size of the standard contract. This final category has experienced enormous growth in the past five years, see CME (2005).

The two electronic contracts, standard size and E-mini, currently co-exist for pricing reasons: for large players the standard contract is substantially cheaper. Despite the rapid growth of the E-minis this paper concentrates on the standard contract due mainly to its importance for the major players; importantly, however, preliminary investigations reveal that many of the patterns observed here are also apparent in the E-mini data.

While it is already known that futures markets lead spot markets in absorbing information, it has also become apparent that electronic trading may lead open outcry, for example Hasbrouck (2003), Kurov and Lasser (2004). Only relatively recently have researchers begun to investigate the electronic out of hours trade in futures, see Barclay and Hendershott (2003). We describe the activity of the after-hours equity futures market in some detail in Section 2. The market shows clear characteristics of higher trade volume, volatility and price changes with news releases when those news releases occur outside the regular trading hours.

The market is found to be most active in terms of transacted volume and volatility in the two hours immediately preceding and immediately following the opening hours of the NYSE. These are hours that we regard as dominated by US factors, whether "news" from the US or reactions to overnight events by the US markets, and are also the hours in which many of the ECNs operate their extended market hours. The Asian trading period (from 19:00 to 1:00 CST) exhibits little activity, but the market is significantly livelier in the European space (from 1:00 to 6:30 CST) although not comparable to the pre-open US period. However, the greatest price impact revealed by the VAR methodology of Hasbrouck (1991) is uncovered in the thinner volume, post-close period. Price impact during after-hours trading otherwise is relatively low.

The paper proceeds as follows. Section 2 describes the features of the out-of-hours equity futures contracts for the S&P500 and NASDAQ 100. Section 3 characterises the volume of trade in these contracts, including the importance of news effects, while Section 4 turns to measures of price impact in the different time zones, and measures of informed trading are discussed in Section 5. Section 6 concludes.

2. Round-the-Clock Equity Futures Markets

Strong linkages between equity markets across time zones are well documented. In general, price spillovers occur as price changes in the foreign markets (and relevant information) are incorporated into the local market (Solnik, 1983; and Cho et al., 1986 on stock markets). In this vein, Eun and Shim (1989) study linkages among the standard trading hours for nine developed stock markets and report evidence of market innovations from the US flowing to the other markets, with limited evidence of foreign market influence back to the US market. Recent studies of ECNs have concluded that trade out of regular trading hours improves price discovery and efficiency in the regular market but that higher trading costs deter maximum price efficiency outside of hours, see Barclay and Hendershott (2003), Barclay, Hendershott and Jones (2006).

Rapid development in technology has permitted the move from floor-based markets to screen-based systems. In most markets the transmission to electronic trade has resulted in the complete loss of floor trading. However, in a couple of instances both survive contemporaneously, notably in instruments traded on the Chicago Mercantile Exchange (CME). For a number of equity futures contracts based on the S&P 500 and the NASDAQ 100 an open outcry pit operates during the regular trading hours of 8:30am until 3:15pm Central Standard Time (CST). A second screen-based system operates through the Global Exchange (GLOBEX) Trading System.[1] A

[1] GLOBEX is an international, automated order entry and matching system which has a network extending to ten financial centers, including New York, Chicago, London, Tokyo. It opens almost 24 hours a day with down times from 4:30 to 5:00 pm CST daily for maintenance and weekend closure from 3:15 pm CST Fridays to 6:00 pm CST Sundays.

summary comparison of the behaviour of the electronic market and the open outcry market is found in Coppejans and Domowitz (1999) using E-minis data. A plausible reason for the continued existence of the two markets is the higher transactions fees in the after hours trading, (see the CME website for details of pricing structures which vary with type of market participant, volume transacted and instrument), but can be generalised to the extent that out of hours trading is more expensive than during regular trading hours.

[Insert Table 1 about here]

The sample of this paper concerns S&P500 and NASDAQ 100 futures contracts which have cash settlement in March, June, September and December on the close of the final trading day in each period, usually the Thursday closest to the 15th of the month. Activity and interest in this market is growing rapidly, see CME (2005). The CME also report spectacular growth in options traded on these products since their introduction in late 2003. The basic characteristics of the contracts are given in Table 1.

The data for this paper have been obtained from the CME and comprise unsigned trades posted on GLOBEX Trading System. The sample covers the period from January 2003 to September 2006, which in the case of the S&P500 contract involves some 2 million observations, and for the NASDAQ 100 about 20% of that at just over 437,000 observations.

Our choice of the standard rather than E-mini contract is based partly on the consideration that large market players continue to transact substantial positions in the standard contract. Although Hasbrouck (2003) has revealed that the E-minis dominate price discovery over the open outcry movement there has not, to our knowledge, yet been a study comparing the E-minis with the standard contracts. Part of the attraction of comparing E-minis with the pit-contracts is that they are both open contemporaneously, so that it is possible to examine their relative efficiency, as in Hasbrouck (2003) and in Coppejans and Domowitz (1999).

The standard contracts traded on the pit and electronically do not overlap in their trading periods between the open outcry and electronic markets; they are the same contract but traded on different trading platforms with different clearing fees, although a trader can easily change positions by operating on either platform. The relative cost advantage of operating in the standard contract during regular trading hours and the ability to use the same instrument in the after hours trade account for the continued liquidity in the electronic after-hours market, despite the gains of the E-mini.

The differences between the open outcry and electronic markets do mean that it is more difficult to construct comparisons on trading volume analogous to those constructed for ECN trades on the NASDAQ by Barclay and Hendershott (2003). On the other hand, the GLOBEX platform truly completes the out of regular trading hours time zone, as opposed to ECNs which merely extend the trading day (closing around 8pm EST and opening around 6.00am EST, although recently opening has begun as early as 4:00am EST to catch the European trading zone).

3. After-hours volume

Figure 1 illustrates the average daily volume transacted in the S&P500 and NASDAQ 100 futures contracts across a day for the period of January 2003 to September 2006, with the units given as the number of contracts transacted. The horizontal scale is the 24 hour clock for Central Standard Time, and the dashed vertical lines divide the day into several time zones.

[Insert Figure 1 about here]

These time zone designations are given in Table 2 in a 24 hour clock for both CST and GMT for ease of conversion (EST is the equivalent of CST+1 hour). These times do not correspond to the full normal trading hours of exchanges in those markets, with the exception of the Chicago pit period. The global trading day for both equities begins at 09:00 local time in Tokyo, which is 19:00 CST. At 01:00 CST trading passes to London, where it is 07:00 GMT. Immediately prior to the opening of the pit market, and aligned with 07:30 am in the New York markets, trading is designated as the pre-open period at 06:30 CST. This continues until the close of the GLOBEX trade immediately prior (but with a 15 minute gap between) the open of the Chicago open outcry pit at 08:30 CST. GLOBEX based trade resumes at 15:15 CST and we denote the period until 19:00 CST as the post-close period. Within that period the GLOBEX system closes for maintenance everyday between 16:30 and 17:00 CST.

[Insert Table 2 about here]

The electronic market displays a distinct intraday pattern. During Tokyo trading hours there is no evidence of volume spikes, and the market essentially remains quiet until European trade begins when a prominent rise in volume occurs at 02:00 CST (08:00 GMT). The pre-open period is the period of consistently highest average trading volume per day on the Globex platform.[2] The spike in volume in the pre-opening period is pronounced, and despite being only one-tenth of the after-hours trading day accounts for almost 30% of the total volume transacted per day over the sample period. Post-close trade is also relatively high.

A comparison of Figure 1 with the corresponding trading time breakdown for NASDAQ stocks in Figure 1 of Barclay and Hendershott (2003) is revealing. Their figure covers the extended trading day from 06:00 EST to 20:00 EST for the top 250 NASDAQ stocks by volume for the period March to December 2000. Despite the differences in data source and sample period the figures show a somewhat similar pattern, with a large morning volume peak and a smaller immediate post-close volume peak. However, there are important differences in the timing of the volume peaks in the two samples. In the spot NASDAQ data of Barclay and Hendershott the peaks occur at 09:30 EST, *after* the opening of the pit. The pre-open trade is relatively smaller, although they do record that it triples between the half hour beginning 08:00 and 08:30, (by way of comparison the trade volume in the futures data rises by 73% and 78% for the S&P500 and NASDAQ respectively). The post-close peak in our Figure 1 occurs at 15:30 CST, which is an hour later than the post-close peak Barclay and Hendershott (which is 15:30 EST). The fact that the secondary peaks in both markets occur immediately after the close suggests that there is something about the

[2] Although their study omitted non-trading hours, Coppejans and Dommowitz (1999) also noted the high volume immediately prior to opening, which they attributed to pre-opening positioning in the absence of a formal pre-opening mechanism such as found in other markets.

closing that is important to volume, rather than the release of information which should hit both markets simultaneously.[3] One possibility is that market participants desire the anonymity which can come via the electronic after-hours market and are willing to pay the higher cost. [4] This prospect is scope for future work in linking to a behavioral finance model.

[Insert Table 3 about here]

Table 3 gives the average daily volume in each time zone in terms of the number of contracts traded. Unlike the after-hours trade analysis in the NASDAQ by Barclay and Hendershott (2004) who report an average of only 100 transactions per day in each of the pre-open and post-close periods, there is a substantial volume transacted during the after-hour periods. The current dataset reveals that the average number of contracts traded in the pre-open period each day is almost 730 for the S&P and 187 for the NASDAQ. The lowest trading period is the Tokyo period, which is also the longest of the samples in the day, pointing to very low liquidity in this time zone. The final two columns of Table 3 give the average number of trades per minute for each of the time period. To make some comparison with the open outcry pit, Hasbrouck (2004) records an average of 12 transactions per minute for the S&P500 contract.

In after-hours trading, the London time zone trades the greatest number of contracts for both instruments - at some 3 contracts per minute. The shorter, more intense pre-open period records an average of 6 contracts per minute.

Clearly the S&P500 futures contract has lower volume in the after-hours than regular trading hours period, but the difference is nowhere near as extreme as that recorded in the ECN data to date. The NASDAQ figures are not as impressive; in

[3] This observation is based on the average of data from two different samples and data sets. Ideally the two sample periods would correspond, however it seems unlikely that this will affect the outcomes presented here.
[4] We are grateful to participants at the Federal Reserve Bank of Atlanta – Cambridge- RPI Conference on Financial Integration in November 2007 for discussions on this possibility. Speculative activity is also a possibility in this market, although it is usually ignored in most analysis of market structure. Day traders are, however, arguably less present in the larger contract future indices under examination here than in the E-minis market (a Google search on day trading and E-minis brings up over 100,000 entries).

London there is less than one contract per minute trade, but again this doubles to almost 1.6 per minute in the pre-open trade.

The pre-open period can potentially incorporate a lot of information, in part due to the generally greater number of traders active in the US time zone, but not least due to the presence of important news releases at 08:30 EST (07:30 CST), corresponding precisely to the timing of the spike in the volume data.

Immediately following the close of the CME at 15:15 CST (which is equivalently 16:15pm EST) there is a surge in activity. This average picture masks a slightly more complex set of scenarios. On many days there is little activity post close. In some days, however, relatively high volume occurs until just prior to the GLOBEX shut down at 16:30 CST.

[Insert Figure 2 about here]

The distribution of the number of contracts traded in this period is shown in Figure 2, there is clearly a long right tail in the distribution representing infrequent large numbers of contracts traded in this period, however, the average is not far from the median in both markets. There are two potential explanations for the trades in this period, either as informed trading in response to after hours news releases or liquidity trading as traders rush to close their books prior to the potentially expensive exposure to overnight trading; in all probability there are elements of both types of trade present. Combining the current results with the evidence in Barclay and Hendershott (2003) which also shows a volume peak just post-close, but at an hour's remove from the current application is suggestive that news cannot be the total explanation.

3.1. Morning News Effects

Major US economic announcements have been documented to affect a large number of financial markets, including foreign exchange (Payne, 1996), bonds (Fleming and Remolona, 1999) and equities (Becker et. al., 1995). Most US economic news is released at 7:30CST (the other scheduled release times of 9:00CST and 1:00 CST do not concern the current sample).

[Insert Figure 3 about here]

Figure 3 shows the corresponding volumes traded for the average news and non-news day in the current sample days for the S&P index, the patterns in the NASDAQ are similar. The news days are categorized as those days on which any of the following major macroeconomic announcements are released: PPI, retail sales, GDP, non-farm payrolls, CPI. The peak in pre-open volume shown in Figure 1 is clearly related to news events, and there is some evidence that news impacts the post-close volume slightly also. Volume on those days is substantially higher than on the non-announcement days - for reference compare the vertical scale of Figure 3 with that of Figure 1.[5]

3.2. Afternoon News Effects

One possible reason for the activity in the post-close period is the long standing tradition of company announcements in this period. Originally this was a strategy intended to give markets sufficient time to assess information properly before acting upon it, and so reducing unwarranted volatility. However, with the advent of extended hours trading this is clearly no longer the case, and in fact the announcements may be emerging into illiquid markets. In the current application the instrument is a futures contract on an equity index. No one component of the index accounts for a substantial proportion of the index, and, given the stop rules on exchanges, even a company announcement which results in sufficient change in that company's stock to result in a stop should not directly cause a substantial change in the index. The announcement has to become in some sense systemic (or contagious) or provide information about the general state of the economy to have an impact.

[5] The figures include the day following a public holiday in the data. On these days, some of which contain news announcements, the CME trading hours differ from normal days, usually opening later. This means that there are some trades on GLOBEX recorded after 9:00am for those days. After checking that these days were not on average substantially different to the remainder of the sample, the trades in the post 9:00am time were deleted from the current study, but the usual GLOBEX trading times on those days were not. The pertinent holidays are: New Year's Day, Martin Luther King's Birthday, Washington's Birthday, Memorial Day, Independence Day, Labor Day, Columbus Day, Veterans Day, Thanksgiving, Christmas Day.

Liquidity traders are expected to close positions at the end of trading days, being unwilling to hold the settlement risk and overnight positions. Brock and Kleidon (1992) in footnote 2 of their paper state that, even with the possibility of 24 hour trade (as here), without continuous settlement process traders would still be most likely to wish either to be at a zero or short position overnight. Barclay and Hendershott (2004) show that waiting for cheaper regular trading hours is not necessarily advantageous to liquidity traders, and that there are profits to be made from liquidity provision after hours. The high potential risk of retaining an open position overnight leads to high demand for liquidity at the end of the regular trading hours, and it is plausible that with the extended trading in spot markets due to ECNs and the development of the new 24 hour GLOBEX platform at least some of the post-close volume seen in the equity futures market is liquidity trading. However, comparisons between results for individual stocks and stock indices such as here are complicated by different incentives for trading these different instruments. The price impact results calculated in Section 4 reveal that the post-close market for the equity futures index is relatively expensive trade. It is possible that the characteristics are consistent with a rush to meet end of day limits by the market participants. In this paper, however, we concentrate on the extent to which trade can be ascribed to information arrival.

To examine the potential impact of company news announcements we consider particularly company earnings announcements occurring in the post-close period. Quarterly earnings releases for many large firms regularly occur in the post-close periods during January, April, July and October each year. Denoting each of these four months as the announcement months, Table 4 shows the average number of contracts traded per day during the time period of 3:30 to 4:15 CST in each of the earnings announcement months as a proportion of the average number of contracts traded per day in the 3:30 to 4:15 CST period.

[Insert Table 4 about here]

The data for the earnings months are compared with the remaining months in the year via the column labeled ‘Rest’. Thus the NASDAQ results indicate that the contracts traded in the earnings months are greater than during the total sample (as the ratio is above 1 in each case), and subsequently in non earnings announcement months the ratio of contracts traded is only 0.76 of the total sample. In the case of the S&P 500 the earnings announcement months are also higher than the average for the year and lower in the ‘Rest’. The disparity is not as great with the S&P500 as the NASDAQ - potentially reflecting more high-tech stocks with earnings releases in the post-close period in general, possibly due to their West Coast location. The month with the largest number of contracts traded is clearly October in both indices. This may be a consequence of (previously noted) higher fourth quarter responsiveness to revisions for the next year's outlook (see Cornell and Landsman, 1989). Although the sample averages are higher in the announcement months, the difference is not statistically significant.

In examining the tails of the distributions given in Figure 2, a number of the largest numbers of contracts traded coincide with earnings announcements for the high tech companies, for example IBM, Microsoft, Intel, Google, Yahoo!, Dell, Texas Instruments, which are primarily located on the West Coast of the US. There are however, a substantial number of days in the tails of the two distributions which are out of earnings announcement months and do not seem to be associated with news about particular companies.

For both indices we examined the 24 days in the tail of the distribution, making up 3.3% (3.2%) of the distribution for the NASDAQ (S&P500). The amounts traded in this tail range from 169 to 394 contracts for the NASDAQ and 393 to 1147 contracts for the S&P500. Of these 24 days, 5 occurred outside of the earnings announcement months in the NASDAQ and 9 in the S&P 500.

These days are shown in Table 5; two days were common to both indices (4 February 2003, 25 September 2003). As indicated in Table 5, six of these days could be associated with general economic conditions rather than specific news releases. Most relevant news related to general economic or political news conditions. In particular, for both indices, the following were recorded in news reports: military action against Iraq (6 March 2003); general economic data released earlier in the day (4 February 2003, 14 August 2003, and 23 May 2006); and perceived weakness or merger activity in the technology sector (2 June 2003, 3 February 2004, and 23 May 2006).

[Insert Table 5 about here]

On the remaining 6 days in the tail there was no readily identifiable news generating activity. The mixture of results here, suggests that there is some underlying level of liquidity trade in this market, overlaid with informed trade on the back of news announcements. Market participants clearly find merit in being involved in this market in order to respond to price changes as the result of out of normal trading hours news as well as for end of day trading.

3.3. Weekend Effects

The anomalous behaviour of many asset prices over weekends has been recorded across equity markets. The GLOBEX futures market ceases trading for the weekend on Fridays at 15:15 CST and reopens at 18:00 CST on Sunday evening (which corresponds to 08:00 am Monday morning in Tokyo and 09:00 am in Sydney, local time). Activity in this early Monday morning trading period is reputed to be quite pronounced, as the news of the weekend is absorbed into the market well ahead of the opening of the floor traded futures or spot markets for the equity indices. However, Figure 4 show that the volume of Sunday evening trade in the S&P500 is no more pronounced than that of any other average day, the same holds true for the NASDAQ (not shown here).

[Insert Figure 4 about here]

However, when early Monday morning trade is compared with the average trade on no-news days it is quickly seen that the average volume on Monday mornings is greater.[6] But the Monday morning trade is lower than on the average news day. These results are particularly interesting, as they show how easily market microstructure can be masked. There is a definite weekend effect present in the data but it is not initially evident without specifically accounting for news announcements.

[6] Two Monday mornings in the sample included news announcements. Excluding them from the weekend effects makes little difference to the reported results.

Existing literature also pinpoints the so-called `triple witching days', when index futures, index options and stock options simultaneously expire; and are either paid out or rolled over as high volume days, see particularly Barclay, Hendershott and Jones (2006) who examine the NASDAQ and S&P500 in this context. They find that there is evidence of higher volume in underlying stock movements associated with these indices. The current data are based on the generic index published by the CME (the CME determines when trade switches from the nearest to the next-to-nearest futures contract prior to the expiration date). There is no evidence of higher volume in the pre-open volume in both futures indices on the triple witching days in the current sample.

4. After-hours Price Impact

Information-based microstructure models demonstrate that new information becomes impounded in prices as a result of trading by informed traders. Glosten and Milgrom (1985) and Easley and O'Hara (1987) suggest that trades can signal information - associated particularly with informed traders. Trades, in themselves, could therefore affect the behavior of prices. In after-hours trading when potentially fewer informed traders are active, and volume is lower, there is a strong presumption that price impact will be higher; for example Barclay and Hendershott (2003).

To investigate price impact we adapt the Hasbrouck (1991) VAR methodology to the non-contiguous time zones examined in this paper. The Hasbrouck (1991) model uses a Wold ordered bivariate vector autoregression representation of trade volume and price revision. Specifically the VAR can be represented as

$$By_t = A(L)y_{t-1} + \varepsilon_t \qquad (1)$$

where $y_t = \{x_t, r_t\}$, which are respectively defined as the signed volume traded, x_t, and the price revision, r_t. The matrix B is 2x2 lower triangular with ones on the main diagonal representing the normalization adopted. That is

$$B = \begin{bmatrix} 1 & 0 \\ \beta_{21} & 1 \end{bmatrix}$$

The matrices $A(L)$ are full matrices of lagged impact coefficients and ε_t represent temporally uncorrelated structural shocks to the system where $\varepsilon_t \sim N(0,\Sigma)$ and Σ is diagonal and positive definite. The Hasbrouck method exploits the one to one relationship between shocks to ε_t and contemporaneous changes in y_t to interpret the coefficient, $-\beta_{21}$, as the measure of the initial price impact of a trade. Subsequent values of the lagged coefficients are used to give the transmission path of prices back to equilibrium, that is the impulse responses to the shock. As the data used are transaction by transaction, rather than equally spaced intervals, the critical, but relatively uncontroversial, assumption in the use of this methodology is that the data display covariance stationarity.

This model has been widely applied to considerations of price impact in financial market data. In Hasbrouck (1991) the initial application considers x_t as a variable taking the values of {1,-1,0} depending on whether the transaction is identified as a buy, sell or non-identified transaction. The zero values were then eliminated from the analysis. Hasbrouck also augmented this with actual signed volume and signed quadratic volume. Unfortunately the current data set does not contain quotes or information on transaction direction, and these limitations provide us with several challenges in implementing the Hasbrouck method. In what follows we address the problems of dealing only with transactions based data.

There is now a significant literature on signing transactions when this is not clearly identified in the original data. The quote method (used by Hasbrouck) identifies a buy (sell) as the case when the trade price is above (below) the mid-point of the prevailing bid and ask quotes. The tick method assigns a buy (sell) to the case where there is an increase (decrease) in the trade price, and takes account of cases where there is no change in price by assigning it the same direction as the previous transaction. More sophisticated algorithms for assigning trade direction are those of Lee and Ready (1991) which is based on using the quote test for trades not conducted at the mid-quote where the tick test is used instead, as also used for example in

Barclay and Hendershott (2004). Ellis, Michaely and O'Hara (2000) further modified this by reducing the role of the quote test to only those trades conducted at the ask and bid prices and expanded the tick test to all other observations.

Some comparisons of the success of these algorithms for trade classification exist, both Finucane (2000) and Theissen (2001) found that the tick test did not underperform compared with the Lee and Ready (1991) tests, while Ellis, Michaely and O'Hara found that the Lee and Ready test improved classification by some 5 percent of observations over the tick and quote tests, and their own innovation improved on this again. Madhavan, Ming, Strasser and Wang (2002) compared the Lee and Ready and the Ellis, Michaely and O'Hara tests finding that dominance of one or other depends on the market under consideration. Unfortunately, in the current dataset there are insufficient observations on quotes to use the quote based methods, so the tick test is the only one available. It is worth noting that the above papers report correct classifications of around 75-80% of transactions via the tick method, and perhaps a further 5% improvement using the more sophisticated combinations of quote and ticks.

The absence of quote data may potentially produce a more important problem than simply signing the trade. Bid-ask bounce may seriously distort the structure of the covariance matrix in the sample data away from that of the true underlying price process, introducing negative serial correlation into the returns process. Hasbrouck (2004) provides a simple demonstration of the potential extent of the problem. Consider the case where bid and ask prices are separated by an execution cost, c, and the preferred mid-quote data distributes these costs equally on either side. When transaction data are used these execution costs are implicitly assumed to be zero, and this understatement is evident in non-zero autocovariance terms between the returns. Following Hasbrouck (2004), the observed price, p_t is

$$p_t = \begin{cases} b_t & if \quad q_t = -1 \\ a_t & if \quad q_t = +1 \end{cases},$$

where b_t and a_t represent the bid and ask prices, and q_t is the trade direction. The underlying process driving these observed prices is given by the efficient price, m_t

which is a random walk with random news arrival u_t ~N(0,σ^2), and execution costs, so that $b_t = m_t - c < m_t + c = a_t$. In this case, one means of estimating the execution cost, c, is via the expression for the autocovariance of the returns. Period by period returns under this model can be expressed as $\Delta p_t = c\Delta q_t + u_t$ and the assumption of independence between the execution cost and the news arrival means that the autocovariance for the returns is given by $Cov(\Delta p_t, \Delta p_{t-1}) = -c^2$. Hence, the autocovariance properties of the data give an estimate of the execution cost under the assumptions of the model.

However, the form of the particular model is quite restrictive, and does not specifically account for the clustering of arrivals seen in data or that the execution costs may be time varying or asymmetric. Hasbrouck (2004) proposes a Markov Chain Monte Carlo approach to take into account the distribution of execution costs potentially evident in the sample. Using relatively uninformative priors, simulations of the data are drawn using a Gibbs sampler to generate a posterior density over the unobserved trade direction from the observed price data. The method requires a specification of the price formation process, such as given above. Hasbrouck uses this simple case to compare measures of the execution cost from the autocovariance properties of sample data on four futures contracts with Bayesian estimates of execution cost and finds that the former seem to be a major overestimate of c. The source of this bias is the independence assumption in the expression for the autocovariance given above – in deriving such an expression we assume independence between news and trade direction in non-contemporaneous periods, but this is not explicitly imposed in the Bayesian estimates. Clearly the model results suggest there is substantial feedback between news and direction of trade across successive transactions.

Despite the insights it offers, the simple model is unlikely to be satisfactory. In a slightly more complex specification, where traders take into account the information revealed by previous price impact in determining the efficient price, the estimate of execution cost is slightly higher, although still well below that of the autocovariance properties of the sample. Hasbrouck concludes that the Bayesian estimates of the execution costs are generally in the same direction as those generated by the simple sample properties, and it seems likely that the latter are substantial overestimates of the true values. The use of Bayesian techniques to estimate trade direction is a promising area of future research for the case where only transaction data are available. It requires a strong model of the underlying price process including distributional assumptions, and technical implementation is not always straightforward due to difficulties with empirical convergence. What currently does seem clear is that the autocovariance properties of the sample provide an overestimate of the cost, while it is not yet evident how much of the observed price change should be assigned to direction of trade, and how much to other costs.

To get an idea of the potential extent of the problem of non-zero execution costs in the current application we calculated the sample autocovariances for the NASDAQ and S&P500 returns for each time zone. The results given in Table 6 show relatively small execution cost estimates, with those for the S&P500 about one quarter of the estimates for the NASDAQ. Additionally, there is some evidence that the costs are slightly higher during the pre-open period compared with the other subperiods, reflecting the desirability of trading in this period when there is often significant public news arrival. An estimate using Bayesian techniques is left for future research, at this stage having ascertained that there is some degree of the problems identified by Hasbrouck present in the current sample.

[Insert Table 6 about here]

To investigate the price impact effects during different time zones it is necessary to control for the cross day effects. This was done by trimming the observations in each sub period sufficiently to include the desired lags within the period - to avoid crossing either days (which happens with the introduction of a simple day change dummy) or time zones.[7]

The contemporaneous and cumulative price impact from a VAR(5) specification of equation (1) are reported in Table 7 for each of the time zones, where x_t is the

[7] An alternative specification would be to treat the VAR as the same throughout the after-hours trading and introduce a series of time zone dummies akin to the approach of Dufour and Engle (2000) who include time of day dummies. Experiments along these lines proved unsatisfactory due to the difficulty in controlling for lag effects across the different periods.

signed trade volume (not the sign of trade as in Hasbrouck's original estimates), based here on the transactions prices rather than mid-quotes as discussed previously. The cumulative impulse responses reported are calculated for the 20th period horizon, which is representative of time horizons from 10 periods onwards. Sensitivity analysis to including additional variables in the form of the sign of trade and the signed square of traded volume to account for nonlinearities, as suggested in Hasbrouck, did not make a discernible impact on the coefficients reported in Table 7, nor did changes in the lag structure of the VAR have a substantive impact. The choice of a VAR(5) follows the existing literature such as Dufour and Engle (2000) as standard information tests tend to suggest excessively long lag lengths. The existing literature is ad hoc in its choice of lag length, with lags out to as far as 100 transactions in some cases.

[Insert Table 7 about here]

In all after-hours trading zones the price impact is positive and statistically significant at 5 percent for both indices. The significance of the price impacts is robust to the potential problems with the covariance matrix associated with the transactions data, bootstrapping does not change these results.[8] The initial price impact in Tokyo shows that a one unit buy trade is associated with a price increase of 0.0137 in the S&P500 futures index and 0.0465 in NASDAQ futures. In London the initial price impact is slightly lower for both indices. The most interesting periods are the pre-open and post-close. In the pre-open period, which has already been seen to be high volume, and particularly influenced by macroeconomic news announcements, the initial price impact coefficient is statistically significant for both markets at 0.0109 and 0.0376 for the S&P500 and NASDAQ respectively. However, in the post-close period the price impact in both markets is statistically significantly higher, at 0.0113 for the S&P500 and 0.0492 for the NASDAQ. However, the price impact in the post-close for the S&P500 remains below that of the Tokyo and London time zones. The cumulative price impacts reported show a similar pattern,

[8] The estimated covariance matrices of residuals in each VAR are strongly diagonal in each case, there is no substantive evidence of non-zero covariance terms.

During the pre-open period the price impact is significantly lower than price impact in the other time zones considered. This is the highest trading volume period. Price impact during the period of next greatest volume, the post-close is significantly higher, and in the case of the NASDAQ the highest of all the periods considered. This is a low volume trading period, on average no greater than volume in either Tokyo or London. Barclay and Hendershott (2004) find the opposite result for individual stocks, in that the initial price impact in individual stocks is higher in the pre-open than post-close period when measured using effective spreads (although comparisons across different instruments, such as between equity futures and individual stock prices are difficult to make).

5. Public and Private Information in After-Hours Markets

The two periods of particular interest in after-hours trading are the pre-open and post-close. A potential difference between these periods is the type of information released. In the post-close period information is often likely to be company or sector specific, relating to outcomes in particular stocks. In the pre-open period, as seen above, information is most likely to relate to public announcement of macroeconomic aggregates. These two types of information may be treated quite differently in the markets. Potentially the highly active pre-open period announcements are very public and traders are relatively well informed on their impact and have pre-formed expectations on how they will react, so the information in the sense of asymmetry between players is less pronounced than for company specific announcements which may occur in the more thinly traded post-close market.

Easley, Kiefer and O'Hara (1997) develop a means of assessing the proportion of informed and uninformed (or liquidity) trades in total trading activity using the proportion of informed trade measure deducted from trade direction, or PIN (Probability of INformation-based trading). This relies on a Bayesian tree stylized analysis of how markets react following news arrival. Unfortunately the methodology does not transfer well into our application, producing only corner solutions.[9] Recently, Benos and Jochec (2007) have thrown empirical doubt upon this measure.

The standard vector moving average representation of a VAR facilitates a forecast error variance decomposition of the sources of movements in variables under the assumption that the shocks are independently distributed. Previous authors have interpreted the contribution of volume shocks to variation in returns as the proportion of price discovery due to private information, see Barclay and Hendershott (2003).

[Insert Table 8 about here]

The results presented in Table 8 suggest that the role of private information is around one-third of total. For the pre-open period this is similar to that observed in Barclay and Hendershott (2003) who examine electronic trading for individual NASDAQ stocks out of hours. However, they find a relatively smaller private information component in the post close, at around 25%, whereas in the current work the share is relatively unchanged across all the time zones.[10]

6. Conclusion

This paper has considered the after-hours trading market for CME equity regular futures contracts on the S&P500 and NASDAQ 100 traded on the GLOBEX electronic platform. To our knowledge it is the first paper to study such a market. In equity markets the spot market ECNs cover extended hours but not full 24 hour trade. Volume in electronic trade in futures was shown to be highest in the two periods immediately surrounding the opening hours for the CME pit for these instruments, notably from 6:30am to 8:15amCST and 3:30pm to 7:00pmCST (christened the pre-open and post-close periods). High volumes in the pre-open period were shown to be particularly associated with anticipated macroeconomic news releases for the US economy, which occur at 8:30EST prior to the opening of the spot trading floor. Informed trade seems to contribute approximately equivalently during all time zones

[9] The PIN takes the value of 1/3 when each of the estimated parameters takes a corner value of one. Investigations revealed that this was particularly the case as the number of observations increased.

[10] The horizon for the variance decomposition makes very little qualitative difference as the results settle to the decompositions reported here very quickly.

across the day. However, price impact was shown to be statistically significantly higher in the post-close period than the pre-open. If liquidity traders do need to settle overnight positions in the post-close trade it may be relatively expensive to do so, and if this is being done as a means of preserving anonymity in the market, then it provides a direct measure of the cost of that service.

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Table 1
Characteristics of the S&P500 and Nasdaq futures contract Globex trading

Contract size	Nasdaq: $100 times the index S&P 500: $250 times the stock price index
Minimum fluctuation	1 point = $2.50
Contract listing	March, June, September, December
Last day of trade	Thursday prior to third Friday of contract month
Trading limits	5.0% increase or decrease from prior settlement price
Trading hours	
Monday-Thursday	5:00 pm CST - 8:15 am CST 3:30 pm CST - 4:30 pm CST
Shutdown	4:30 pm CST - 5:00 pm CST
Sunday and holidays	5:00 pm CST - 8:15 am CST

Source: CME web page: www.cme.com, www.spglobal.com

Table 2
Designated time zones and trading hours in CST and GMT

Designated time zone	CST hours	GMT hours	number of hours
Tokyo	19:00 - 01:00	01:00 - 07:00	6
London	01:00 - 06:30	07:00 - 12:30	5.5
pre-open	06:30 - 08:15	12:30 - 14:15	1.75
Chicago pit	08:30 - 15:15	14:30 - 21:15	6.75
post-close	15:15 - 19:00	21:15 - 01:00	3.5
market closure	16:30 - 17:00	22:30 - 23:00	0.5

Table 3
Average daily volume in different timezones for the S&P 500 and Nasdaq 100 futures contracts (January 2003 to September 2006)

Timezone	number of contracts		trades per minute	
	S&P 500	Nasdaq	S&P 500	Nasdaq
Tokyo	277.2	99.8	0.77	0.28
London	1072.4	259.2	3.25	0.79
pre-open	729.9	187.5	6.08	1.56
post-close	277.2	115.4	1.69	0.55
total after-hours	2435.4	661.9	2.39	0.65

Table 4
Average contracts traded per day in the period 3:30 to 4:15 CST in each index by month as a proportion of the total average contracts traded per day in the period

	S&P 500	Nasdaq 100
January	1.26	1.53
April	1.14	1.50
July	1.04	1.29
October	1.35	1.61
Rest	0.90	0.76

Table 5
Large trading volumes occurring in non-earnings announcement months and associated news

Index	Date	Trades	News
S&P	04-Feb-03	363	manufacturing growth
ND		640	
S&P	27-Feb-03	512	
ND	06-Mar-03	211	Iraq
S&P	02-Jun-03	609	software company mergers, biotech
S&P	05-Aug-03	420	
S&P	14-Aug-03	1015	beginning data and rising Treasury yields
S&P	25-Sep-03	453	
ND		171	
ND	03-Feb-04	240	manufacturing, weakness in technology sector
S&P	10-Aug-04	451	
ND	02-Dec-04	178	
S&P	31-Oct-05	393	
S&P	23-May-06	567	weakness in technology, economic growth

Table 6
Estimate of execution cost from autocovariance of the sample price data,
$c = \sqrt{-Cov(\Delta p_t \Delta p_{t-1})}$

	S&P 500	Nasdaq
Tokyo	0.039	0.151
London	0.036	0.142
pre-open	0.045	0.152
post-close	0.041	0.168

Table 7
Initial and cumulative 20th period price impact for the S&P 500 and Nasdaq 100 futures contracts
(July 2002 - September 2006)

	S&P 500		Nasdaq 100	
Timezone	price impact $-\beta_{21}$	cumulative price impact 20th period	price impact $-\beta_{21}$	cumulative price impact 20th period
Tokyo	0.0137	0.050	0.0465	0.1813
London	0.0132	0.041	0.0405	0.1571
pre-open	0.0109	0.038	0.0376	0.1374
post-close	0.0113	0.040	0.0492	0.1550

Note: All estimates are statistically significant at 5%

Table 8
Proportion of private information variance decomposition (% of total variance in returns due to shocks in volume traded at the 50 observation horizon)

	S&P 500	Nasdaq
Tokyo	31.21	33.65
London	31.16	33.29
pre-open	31.49	32.65
post-close	28.26	33.11

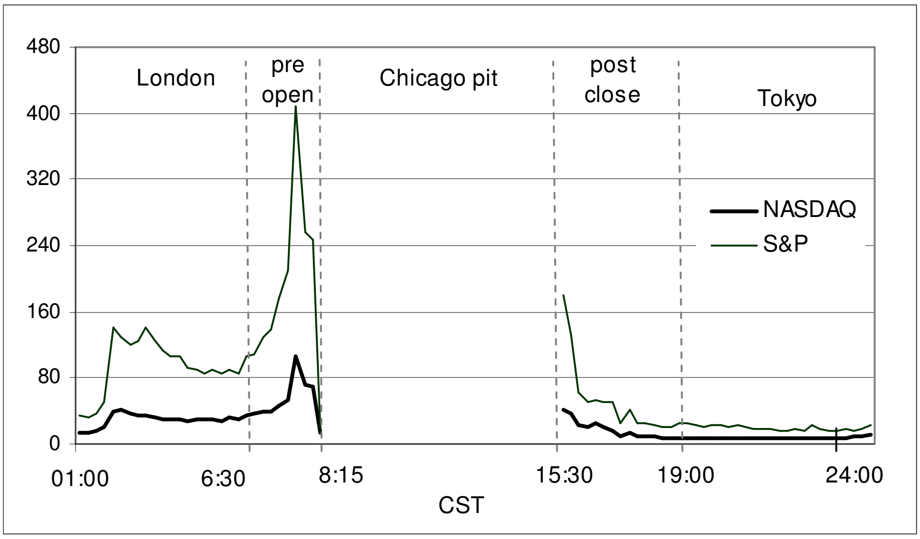

Figure 1: Average Volume in S&P500 and Nasdaq 100 futures contracts by 15 minute interval (January 2003 - September 2006)

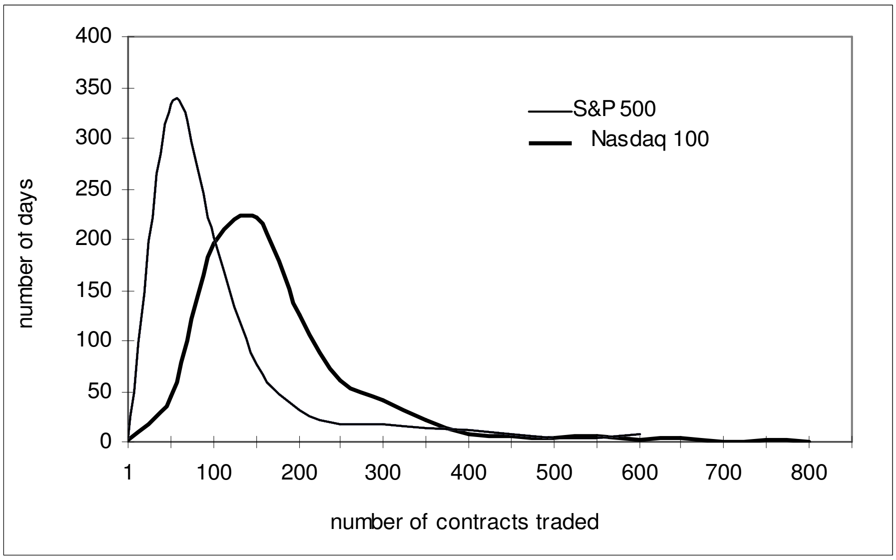

Figure 2: Distribution of the number of S&P 500 and Nasdaq 100 contracts traded in post-close time-zone (3:30 till 4:15pm CST)

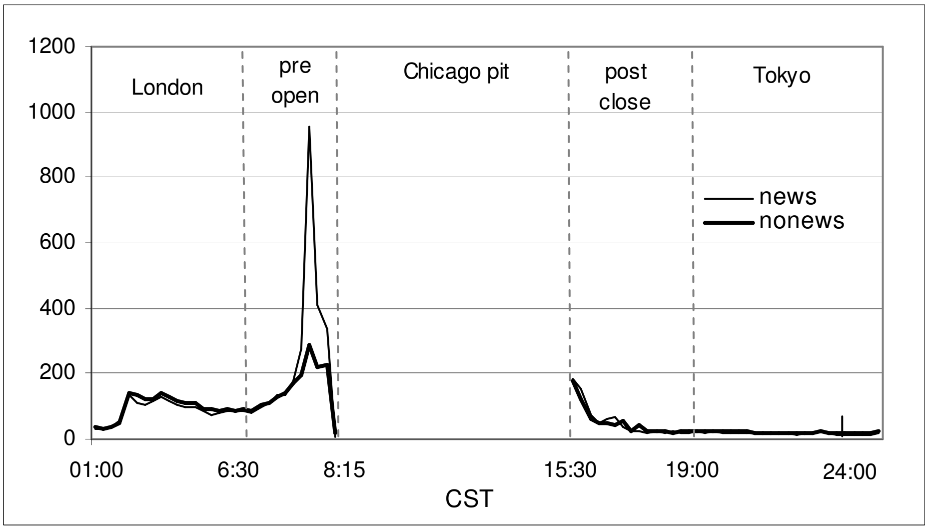

Figure 3: Average Volume in S&P500 futures contracts on news and no-news days, January 2003 - September 2006

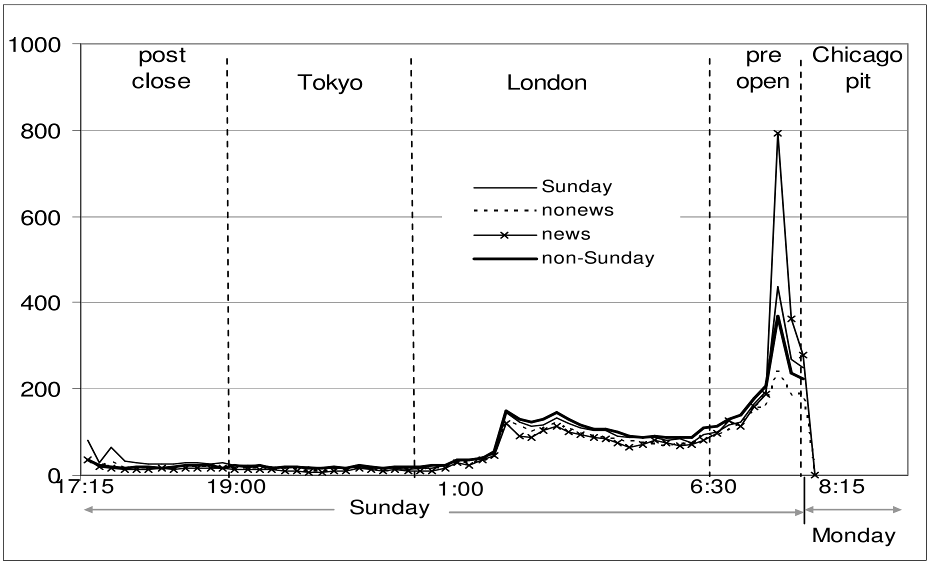

Figure 4: Average volume: Sunday, non-Sunday, news, and no-news days