LIQUIDITY AND TRADING ACTIVITY OF EQUITY OPTIONS: HEDGING COST AND TIME SERIES EFFECTS

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Abstract: This study utilises an extensive intraday dataset from two European exchanges, namely NYSE LIFFE Amsterdam and London, to study the effect of hedging on the liquidity of single stock options. We show that the behaviour of spreads and depth are consistent with the derivatives hedging theory. After decomposing hedging costs to the initial and rebalancing costs, we show hedge rebalancing costs are much more strongly associated with option liquidity. There is little evidence that the inventory cost component of spreads is associated with changes in liquidity. Instead, we show that option open interest captures informed trading effects and that spreads are associated with economies of scale in order processing costs. Finally, we show that bid-ask spreads, depths and trading activity vary considerably over time. Both liquidity and trading activity indicators appear to report a sharp decline following a short sale ban and also during the implementation of the European rescue funds that led to volatility spikes.

Keywords: market microstructure, LIFFE, options, liquidity, bid-ask spread

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1. INTRODUCTION

Liquidity and trading activity are reliable indicators of the sound functioning of financial markets, e.g. decreases in liquidity are associated with increases in the cost of capital and the required rate of return. In options markets, liquidity is related to underlying market activity hence it is closely linked to hedging costs (Cho and Engle, 1999).

In the only prior research that explicitly models liquidity determinants for individual equity options, Wei and Zheng (2010) study options trading at U.S. exchanges. The authors report that option volatility is the most important determinant of option liquidity, linking option volatility with inventory risk faced by market makers. Also, the explanatory power of the stock bid-ask spread is weak relative to option volatility, which the authors attribute to inventory management practices. In this study, we refute the findings of Wei and Zheng (2010) on the basis of the salient market structure of NYSE LIFFE.[2] The single stock options market at NYSE LIFFE operates an "open system", order-driven architecture with registered trading members and competing liquidity providers. We use data from two different exchanges, namely NYSE LIFFE Amsterdam and London, to test alternative hypotheses and interpretations.

We show that the findings of Wei and Zheng (2010) regarding the association between option volatility and liquidity in the US option markets can be explained by the derivatives hedging theory. Our regression results show that, in contrast to what is hypothesized by the inventory management theory, spreads widen on increasing levels of trading volume. The latter is likely

[2] Wei and Zheng (2010) do not provide a comprehensive discussion on the market structure which generates their dataset.

to arise because increased volume captures increases in informed trading (see Engle and Neri, 2010). Spreads widen and depths decrease with increases in transaction frequency, reflecting economies of scale in the order processing costs. Option open interest captures informed trading effects in the options market. Overall, we are unable to find clear evidence that the initial costs of hedging asset positions with the underlying assets is a strong determinant of option liquidity and trading activity. Instead it is shown that the initial hedging cost reflects a price level effect in options. However, our results strongly support the hedge rebalancing hypothesis, hence we confirm that increases in the cost associated with rebalancing hedged positions are associated with a widening of spreads.

Further, we study the time series properties of liquidity and trading activity of single stock options in European markets. We show that liquidity and trading activity measures vary considerably across Amsterdam and London. Also, both liquidity and trading activity indicators demonstrate a sharp decline during the events following a short sale ban and also during the implementation of the European rescue funds that led to volatility spikes.

The rest of the paper is organised as follows. Section 2 discusses the position of the paper within the literature. Section 3 discusses data selection issues and variable construction. Section 4 presents the empirical findings and Section 5 summarises the paper.

2. POSITIONING OF THE PAPER

Several studies identify the determinants bid-ask spreads on securities and a general consensus exists that this is a function of the order processing cost (Demsetz, 1968), the inventory management cost (Garman, 1976 and Stoll, 1978) and the asymmetric information or adverse selection cost (Copeland and Galai, 1983, Kyle, 1985 and Glosten and Milgrom,

1985).[3] For options, a more recent derivative hedging theory has emerged that links option market liquidity with the underlying market activity (see Cho and Engle, 1999).

The inventory management theory postulates that dealers will adjust their spread in order to rebalance their inventory position due to large order imbalances. Spreads widen with factors that may affect inventory balances: trade size and volatility. Based on theory, one would anticipate that an increase in the option trading volume narrows spreads as the higher volume lowers the risk of order imbalances. Also, option return volatility is positively correlated with inventory risk. The order processing cost theory refers to the fixed cost that dealers face when trading in the market (Demsetz, 1968). Engle and Neri (2010) and Petrella (2006) use the number of transactions per interval as a measure of order processing costs. Order processing costs are relatively fixed, hence spreads widen when the number of trades decreases.

Asymmetric information models postulate that if certain investors have superior information, spreads may widen in times of high uncertainty as traders and dealers want to protect themselves from trading with informed investors (see Copeland and Galai (1983), Chakravarty et al. (2004), Kyle (1985), and Glosten and Milgrom (1985)). Engle and Neri (2010) use the probability of informed trading in the stock market as a proxy of informed trading in the options market.

Cho and Engle (1999) argue that hedging is of primary concern to investors in the derivatives markets and options spreads are a function of the spread in the underlying market: the more difficult it is for investors to hedge their net positions by deriving liquidity in the underlying market, the greater will also be the spread variability in the derivatives market. In contrast to

[3] An excellent review of the literature on asymmetric information and inventory models can be found in Madhavan (2000). The empirical literature in support or against of these models is also extensive. Several studies exist regarding the intraday variation of returns (e.g. Harris, 1986) and of the bid-ask spread (see Chan, Chung and Johnson, 1995).

Wei and Zheng (2010), Cho and Engle (1999) use the elasticity of the option price with respect to the underlying asset price times the underlying spread as a measure of the initial hedging costs. Similar studies by Kaul et al. (2004) and Petrella (2006) show that option spreads are a function not just of the initial hedging cost but also of the hedge rebalancing costs. The derivatives hedging theory predicts that option traders take into account the initial hedging cost required to offset the risk exposure of holding the option contract and also the hedge rebalancing cost which accounts for the rebalancing cost required to maintain a risk neutral option exposure.

A second stream of literature is focused on commonality of liquidity in equity markets following Chordia et al. (2000), in which individual liquidity measures are regressed against a market-wide liquidity factor.[4] Cao and Wei (2010) use daily U.S. data to infer the common liquidity component of all options trading on U.S. exchanges, documenting strong commonality even after controlling for the impact of the underlying stock market. Also, similar to Chordia et al. (2000), a size and volatility effect in liquidity is reported. In general, bid-ask spreads are mostly associated with trading costs, whereas market depth is an indicator of the resiliency of the market to absorb increases in volume (see Vijh, 1990). Vijh (1990) shows that in competitive dealer markets, market depth is offered at the expense of higher bid-ask costs, thus when depths increase, spreads widen as market makers request higher compensation to recover the higher inventory costs of providing greater depth.

In this study, it is hypothesized that market makers' influence diminishes under a "decentralized" trading system. In this respect, we follow the argument of Cho and Engle

[4] See Brockman and Chung (2002, 2006) and Hasbrouck and Seppi (2001). For evidence on commonality in liquidity along the order book see Kempf and Mayston (2008), Rakowski and Beardsley (2008) and Visaltanachoti et al. (2008). Also, Chordia et al. (2001) and Huberman and Halka (2001) report a time-varying component of commonality in liquidity.

(1999) that in a market with sufficient underlying liquidity, option spreads are primarily associated with hedging costs rather than with maintaining inventory positions. As documented by Clyman et al. (1997), volume may not be a good proxy of liquidity in options markets implying that as long as the underlying market contains enough liquidity making it possible to hedge a trade with offsetting positions in the underlying market, spreads in the option market will be very competitive (see also Cho and Engle, 1999). In line with the inventory management theory, Vijh (1990) shows that spreads and depths are positively correlated. We hypothesize that general increases and decreases in liquidity imply a negative association of spreads with depths, hence both variables are studied concurrently, which allows us to study the role of inventory management further. Overall, we test two competing hypotheses: the derivatives hedging theory that implies a strong association of spreads with the underlying market liquidity and inventory management that has been found to be strongly correlated with trading volume.

3. DATA, MEASURES OF LIQUIDITY AND TRADING ACTIVITY AND REGRESSION VARIABLES

3.1. Data

NYSE LIFFE is the derivatives branch of NYSE for the European derivatives market, overseeing a total of five European markets (Amsterdam, Brussels, Lisbon, London and Paris). Trading in individual equity options occurs on the Amsterdam, Brussels, London and Paris exchanges. Trading on NYSE LIFFE is via LIFFE CONNECT, an anonymous, electronic order-driven system. Liquidity on NYSE LIFFE is supported by the "Euronext Liquidity Provider System" (ELPS), a scheme that was originally introduced for the Amsterdam options market and has since migrated to all individual equity contracts traded on

LIFFE CONNECT. ELPS operates on the basis of market makers acting as liquidity providers with the obligation to submit continuous asks and bids in near-the-money contracts and receive trading rebates as a return.[5]

The objective is to create daily time series while utilizing the rich information available from intraday data.[6] We use 34 months of tick data for all individual equity options (henceforth tickers) trading at NYSE-LIFFE Amsterdam and London, from March 2008 to December 2010.[7] The data files contain information on maturity date, strike price, volume and price for every individual equity option, time-stamped to the nearest second, separately for asks, bids and trades. The total number of tickers is 180, however the size of the dataset is further increased by a factor of approximately 1,300 as each ticker is trading under different contracts, which vary by the strike price, maturity date and contract type (i.e. call or put) (henceforth sub-tickers).[8]

We apply several data cleaning algorithms. All zero volume, zero price and out-of-hours observations are deleted.[9] We identify the most recent bid and ask prices for each trade for each sub-ticker. Selecting data with adequate transaction frequency over a long time span can

[5] "How the Euronext.liffe markets work". Available on the NYSE LIFFE site.

[6] This is similar to the approach in Stoll (2000), who uses intraday data for a period of 61 trading days for 3,890 stocks traded at the NYSE and 2,184 stocks traded at NASDAQ.

[7] The value of contracts traded during December 2010 was approximately €12.5m for Amsterdam and €7.4m for London (American-style options only. Source NYSE-LIFFE statistics). Brussels is dropped from the sample as the data selection criteria discussed below result in a sample of only five tickers. Also, in a previous version of this paper, we also use Paris data, however, in order to conserve space, Paris is dropped from the paper (the results are qualitatively similar – available upon request).

[8] All option contracts in the final dataset are American style. The number of tickers reflects the total number of firm-options trading at the exchanges and includes delisted options. The large number of sub-tickers refers to the total number of sub-tickers that are available for each ticker for the entire sample period.

[9] Both exchanges are open between 08:00 and 16:30 (London time). We also delete half-days.

be difficult for individual equity options data. For this reason, we follow a method similar to Chan, Chung and Johnson (1995), focusing on the relative liquidity of tickers and selecting those that are in the top 30% of the average daily number of trades for each market. This process guarantees a large amount of intraday data and excludes less liquid contracts. The final dataset consists of 50 tickers, 20 of which are trading in Amsterdam and 30 in London.[10] Quotes with negative or zero bid-ask spreads are dropped from this sample. Also, as in Wei and Zheng (2010), we control for possible outlying data by dropping quotes with excessively large bid-ask spreads. The cut-off point for the percentage bid-ask spreads is set at 200% for out-of-the money options and 150% for the in-the-money options.

Problems that arise when combining option quote and trade data include quote staleness and errors in the recording of trades (De Fontnouvelle et al., 2003). We control for these problems as follows: trades that involve price changes of 50% or more from the previous price or the most recent midpoint are dropped from the sample. Also, we classify quotes as stale when the subsequent trade does not occur within 10 minutes of the quote time.[11] Finally, we delete trades for which there are no recent quote data (i.e. we require that quotes are updated after each trade) and trades that are priced higher than the most recent ask price or lower than the most recent bid price. End-of-day prices for the underlying stocks and the 3-month T-Bill rate data for each country are obtained from DataStream. We define moneyness on a daily basis.

We calculate moneyness (at the start of each trading day) as the relative difference between the current stock price and the present value of the strike price, scaled by the current stock price:

[10] Three assets were dropped from the regression samples because of missing observations on DataStream which made the calculation of deltas problematic (2 from Amsterdam and 1 from London).

[11] De Fontnouvelle et al. (2003) classify stale prices on 5-minute intervals, however, we have increased this time window as trade frequency for our securities is lower than in the U.S. markets.

$$Mon_{i,tick} = \begin{cases} \dfrac{S_{i,n} - X_{i,tick} e^{-r_n(N_i - n_i)}}{S_{i,n}}, & \text{if call} \\ \dfrac{X_{i,tick} e^{-r_n(N_i - n_i)} - S_{i,n}}{S_{i,n}}, & \text{if put} \end{cases} \tag{1}$$

Where $S_{i,n}$ refers to the underlying asset price for each subticker i at day n, $X_{i,tick}$ refers to the strike price for sub-ticker i at each tick of date n, r_n is the risk-free rate. N_i refers to expiration date and n_i refers to current date. N_i-n_i equals the number of days until expiration. We expect that spreads will differ for different moneyness levels and maturities (see Cho and Engle, 1999), therefore we aggregate our estimates in moneyness and maturity groups. Contracts that fall within the (-0.05, 0.05) range of $Mon_{i,tick}$ are defined as being at-the-money (ATM). In-the-money and Out-of-the-money contracts refer to $Mon_{i,tick}$ greater (smaller) than 0.05 (-0.05).

Also, we control for expiration effects as follows:

$$Exp_{i,tick} = \begin{cases} Very\ short\ term\ (VST)\ if\ (N_i - n_i)\ \leq 7\ days \\ Short\ term\ (ST)\ if\ 7\ days < \ (N_i - n_i) \leq 90\ days \\ Long\ term\ (LT)\ if\ 90\ days < \ (N_i - n_i) \leq 365\ days \\ Very\ long\ term\ (VST)\ if\ 365\ days < \ (N_i - n_i) \end{cases} \tag{2}$$

As anticipated, the bulk of trading is for the ST, ATM contracts and the distribution of trades across moneyness levels for each maturity period varies (results not presented). In order to avoid making inferences across moneyness levels and maturity periods, we limit the analysis to the ST, ATM contracts.[12]

[12] Year-change observations are dropped from this sample (see also Chordia et al, 2001).

3.2. Measures of liquidity and trading activity

We use three different intraday liquidity measures, namely bid-ask spread, effective spread and quoted depth. The most commonly used spread measure is the quoted bid-ask spread, defined as the difference between the most recent ask and bid prices (see Petrella, 2006, Cao and Wei, 2010 and Wei and Zheng, 2010). At each sub-ticker, we control for price level differences by calculating the percentage bid-ask spread ($PBAS_{i,\ 10\text{-}min}$) at 10-minute intervals, defined as the ratio of quoted spread over the quote midpoint:

$$PBAS_{i,10-min} = 100 \times \frac{Ask_{i,10-min} - Bid_{i,10-min}}{M_{i,10-min}} \tag{3}$$

where $Ask_{i\ ,10\text{-}min}$ and $Bid_{\ i,10\text{-}min}$ are the ask and bid prices sampled at 10-minute intervals respectively and $M_{i,10\text{-}min}$ is the trade midquote defined as half the sum of bid and ask prices at each interval.

A second, more direct, measure of transaction costs is the effective bid-ask spread that takes into account the actual trade price and the direction of the trade. Similar to $PBAS_{\ i,10\text{-}min}$, we use the effective percentage bid-ask spread ($EPS_{i,tick}$) for each sub-ticker as an unbiased indicator of the effective spread for panel data:

$$EPS_{i,tick} = 100 \times \frac{2D(P_{i,tick} - M_{i,tick})}{M_{i,tick}} \tag{4}$$

where D is a trade classification dummy and $P_{i,tick}$ is the trade price at each tick. A tick refers to the actual time of the trade and midquotes refer to the most recent bid and ask prices (discussed above). As NYSE LIFFE is an electronic order-driven market, trades are submitted on the quoted prices, hence, D equals one (i.e. a buy order) if the trade is

conducted at the most recent ask and negative one if it is conducted at the most recent bid price (i.e. a sell order).[13]

Earlier studies have documented that a reciprocal measure of liquidity is quoted depth (e.g. Harris, 1990). We measure quoted depth ($Depth_{i,\ tick}$) in number of option contracts per ticker as follows

$$Depth_{i,tick} = \frac{Volume_{Ask,i,tick} + Volume_{Bid,i,tick}}{2} \tag{5}$$

where $Volume_{ask,\ i,\ tick}$ and $Volume_{Bid\ i,\ tick}$ refer to the number of option contracts offered at the ask and bid prices respectively. Effective and percentage spreads and depths are subsequently aggregated to equally-weighted daily averages per ticker (see Stoll, 2000).

As measures of trading activity, we calculate *Volume*, defined as the total number of option contracts per ticker traded per day and *Frequency*, defined as the total number of transactions per ticker per day.

3.3. Determinants of liquidity and trading activity

Inventory cost is proxied by the total number of contracts traded per ticker per day. Order processing cost is calculated as the number of transactions per day for each ticker (see Engle and Neri, 2010). We use open interest as a proxy of informed trading (see also Jayaraman and Frye, 2001). The advantage of open interest over the probability of informed trading is that open interest is unique to the options market and is determined endogenously.

For the initial hedging cost, we calculate continuous option deltas for each asset.[14] We follow Engle and Neri's (2010) specification of the initial hedging cost ($HC_{i,n}$) as the elasticity of the

[13] The 3 percent of data that are not classified are deleted from the sample.

option price with respect to the underlying asset price times the percentage bid-ask spread of the underlying asset:

$$HC_{i,n} = \frac{\partial c_{i,n}}{\partial S_{u(i),n}} \times \frac{S_{u(i),n}}{c_{i,n}} \times 100 \times \frac{Ask_{u(i),n} - Bid_{u(i),n}}{M_{u(i),n}} \tag{6}$$

Where $c_{i,n}$ refers to the daily option price, $S_{u(i),n}$ is the daily underlying price, $Ask_{u(i),t}$ ($Bid_{u(i),t}$) refers to the daily closing underlying ask (bid) price. $M_{u(i),t}$ is the midquote of the daily underlying ask and bid price.

For the hedge rebalancing cost, we use gamma times the volatility of the underlying asset (see Petrella, 2006 and Engle and Neri, 2010).

$$HRC_{i,n} = \Gamma_{u(i),n} \times 100 \times \frac{S^{\max}_{u(i),n} - S^{\min}_{u(i),n}}{M_{s,t}} \tag{7}$$

Where $\Gamma_{u(i),n}$ refers to option gamma, $S^{\max}_{u(i),n}$ ($S^{\min}_{u(i),n}$) is the daily maximum (minimum) price of the underlying asset and $M_{u(i),n}$ refers to the midquote of the daily maximum and minimum price (see Parkinson, 1980).

We use several control variables. Lesmond (2005) and Stoll (2000) show that firm size proxies for inventory control, because larger firm size implies reduced risk for traders in finding a counterparty. Stoll (2000) notes that the asset's price level proxies for price discreteness and also risk because higher priced assets are generally less risky. We include option and implied volatility estimates as proxies of the adverse movement risk faced by

[14] Deltas are calculated separately for ATM calls and puts with a constant maturity of 30 days. Implied volatility, underlying asset price, closing bid, closing ask, strike and option prices and the level of interest rates are downloaded from DataStream. Deltas are calculated using the Black-Scholes formula.

option traders.[15] Contracts with higher moneyness are associated with greater liquidity. Similarly, Cho and Engle (1999) show that option spread is decreasing in time to maturity. Finally, we include dummy variables for the duration of the short-sale ban.[16]

The regression model is of the following form

$$Liq_{i,n} = a_0 + a_1 IC_{i,n} + a_2 OC_{i,n} + a_3 OI_{i,n} + a_4 HC_{i,n} + a_5 HRC_{i,n} + a_6 MV_{i,n} + a_7 OV_{i,n} + a_8 IV_{i,n} + a_9 Pr_{i,n} + a_{10} Mon_{i,n} + a_{11} Exp_{i,n} + a_{12} SS_{i,n} + \epsilon_{i,n} \quad (8)$$

The subscript n refers to days for each ticker.[17] Liq refers to the liquidity variable in question (EPS, PBAS and Depth). IC is the inventory cost, OC refers to opportunity cost and OI refers to information cost. HC refers to the initial hedging cost, calculated as option delta, separately for calls and put contracts. HRC refers to hedge rebalancing cost and is measured as gamma times the volatility of the underlying asset. Pr is the daily closing option price. MV is the log of market value of the underlying asset. OV refers to option volatility and IV refers

[15] A daily measure of option volatility is calculated as the average absolute option return for 30-minute intraday intervals. For the calculation of intraday option returns, we follow the procedure in Sheikh and Ronn (1994). Implied volatility estimates are downloaded from DataStream.

[16] In a separate specification, dummies for the day-of-the week and the days of macroeconomic announcements (see Chordia et al., 2001) were included. However, none of these variables were significant and are therefore dropped from the reported regressions.

[17] Regressions are run separately for each exchange and for option type (calls and puts). NYSE LIFFE is currently in the process of harmonizing the trading rules across the exchanges, however this process is not yet finalized and distinctive differences exist between markets. Unfortunately, the exchange does not publish any market making statistics, especially with regard to the overall proportion of trading that is conducted via market makers. The exchange has confirmed during personal discussions that the Amsterdam and Brussels markets are predominately dominated by non-market makers, whereas the London and Paris markets rely more on the market-making facility.

to implied volatility.[18] Mon and Exp refer to the average moneyness and time-to-maturity respectively per day for each contract. SS is a short selling dummy that takes the value of 1 for the duration of the short sale ban for the assets that were affected by it.[19]

Similarly, we study to what extent the theories developed above explain variability in the trading activity variables. We run separate regressions as follows

$$\begin{aligned} TrA_{i,n} = b_0 + b_1 OI_{i,n} + b_2 HC_{i,n} + b_3 HRC_{i,n} + b_4 MV_{i,n} + b_5 OV_{i,n} \\ + b_6 IV_{i,n} + b_7 Pr_{i,n} + b_8 Mon_{i,n} + b_9 Exp_{i,n} + b_{10} SS_{i,n} + \epsilon_{i,n} \end{aligned} \tag{9}$$

Where TrA refers to the total number of option contracts traded per day or to the total number of transactions per day. The remaining variables are discussed above.

4. EMPIRICAL RESULTS

4.1. The cross section of option liquidity and trading activity

Table 1 reports the summary statistics for the liquidity and trading activity variables. Aggregate measures refer to market-wide, equally-weighted averages of the daily estimates of liquidity and trading activity. We also present the average price level in the final column in Table 1.

*** Insert Table 1 here***

[18] IV and OV are positively correlated but the coefficients do not imply a collinearity problem.

[19] The short selling ban refers to the introduction of regulatory constraints on short sales for several asset classes by many developed exchanges around the world. The ban was initially imposed in September 2008, however the commencement and the duration of the ban was not uniformly applied on different exchanges (see Beber and Pagano, 2012).

Overall, EPS is 8.19bps (8.76) for Amsterdam calls (puts) and 7.59bps (7.7.2) for London calls (puts). The effective percentage spread is less than the quoted spread by construction. The PBAS ranges from 10.2 for Amsterdam to 14.43 for London calls. For puts, the equivalent PBAS estimates are 11.35 and 14.6 for Amsterdam and London respectively. While, for the PBAS, spreads are considerably higher for calls than for puts, this result does not hold for the EPS estimates. The average daily number of contracts offered for Amsterdam is 751.51 (789.87) for calls (puts), which is substantially larger than the equivalent depth measures for London (35.39 contracts for calls and 35.65 for puts).

Traded volume is also higher for Amsterdam than for London. The average number of contracts traded per day in Amsterdam ranges from 1184.1 for puts to 1391.16 for calls. For London, the equivalent figures are 88.77 for puts and 117.2 for calls. Calls are also more frequently traded than puts. Overall, the ratio of volume over frequency is 32.7 for calls and 33.7 for puts for Amsterdam. For London, the equivalent figures are similar (33.3 for calls, 28.6 for puts). The finding that trading volume is higher in Amsterdam nevertheless EPS is also high may reflect the derivatives hedging theory and the finding that volume is not a good proxy for liquidity in options markets (see Clyman et al., 1997).

Table 1 also presents the absolute daily percentage changes for the liquidity and trading activity measures. For both markets, the EPS is more volatile for puts than for calls and it is evident that the EPS is more volatile than PBAS. The absolute daily percentage change of EPS ranges from 10.06 (10.60) for Amsterdam calls (puts) to 20.08 (22.81) for London calls (puts). In contrast to Chordia et al. (2001) for the NYSE, depth is less volatile than quoted and effective spreads. Also, as suggested by Chordia et al. (2001), the trading activity variables are more volatile than the spread variables. Volume daily percentage changes are 47.41 (47.83) for Amsterdam calls (puts) and 91.64 (81.8) for London calls (puts). Changes

in transaction frequency range from 29.83 (27.12) for Amsterdam calls (puts) to 49.68 (45.74) for London.

4.2. Preliminary evidence on the determinants of option liquidity and trading activity

Tables 2 and 3 present some preliminary findings on the determinants of option liquidity and trading activity. Table 2 presents estimates of the liquidity and trading activity variables by exchange, trade type and market value percentile of the underlying stock. The results for the EPS and the PBAS generally confirm that liquidity increases with market value, albeit this relationship is not consistent for all market value percentiles. Similarly, depth generally increases with market value, a sign that larger firms are more liquid than smaller firms. For both markets, the price level generally increases for larger firms, hence an inverse relationship can be inferred between spreads and the price level. Volume monotonically increases with market value. Finally, frequency also reveals a market value effect in aggregate market activity across exchanges and contract types.

*** Insert Table 2 here***

The derivatives hedging theory postulates that spreads will widen with the cost of hedging (Cho and Engle, 1999). Table 3 presents how the average estimates of the liquidity and trading activity variables fluctuate for increasing hedging cost levels. Consistent with the derivatives hedging theory, we decompose hedging cost to the initial cost of setting up the hedge and the hedge rebalancing cost (see Petrella, 2006). Similar to Table 2, we also show the variability of the average option price level in order to offer a preliminary control for the price level effect.

The results for setting up the hedge show that both spread variables are an increasing (decreasing) function of the cost of hedging for calls (puts), albeit this relationship does not hold for all percentiles. Quoted spreads widen within the bottom 50th percentile nevertheless a non-linear relationship arises, a finding that is not consistent with the spread variables reported above. Similarly, trading volume increases with the cost of setting up the hedge, a finding which is reversed however when the hedging cost is at maximum levels. For Amsterdam, transaction frequency is negatively associated with the hedging cost, however this relationship is rather stable for London.

*** Insert Table 3 here***

Panel B presents the results for the hedge rebalancing cost. Both EPS and PBAS show a clear positive relationship between all three liquidity variables and the cost of hedge rebalancing. Also, quoted depth increases with increasing hedge rebalancing costs.

4.3. Time series properties of option liquidity and trading activity

Figure 1 presents the equal-weighted daily averages of liquidity and trading activity variables for calls over the sample period and exchanges. Chordia et al. (2001) show that quoted spreads are negatively correlated with trading activity. Similarly, they show that the spread and depth measures are also negatively correlated.

As EPS and PBAS have a correlation coefficient of 0.9, we omit EPS from the plots. All estimates are standardised by using the sample mean and standard deviation in order to enhance comparability across liquidity and trading activity measures, contract types and exchanges.

*** Insert Figure 1 here***

In Figure 1, Amsterdam demonstrates a dramatic drop in depth in the period September-October 2008. This period coincides with the imposition of the short selling ban in financial markets and is the beginning of a long period of market uncertainty. A similar, yet less substantial, drop is documented for London. Similarly, a second drop in liquidity is documented for the period March-May 2010 which coincides with the agreement between the International Monetary Fund and European Union officials to supply Greece with a "rescue plan" and the credit downgrades of Spanish, Portuguese and Greek government debt. Overall, spreads and depths tend to move in opposite directions, hence periods of illiquidity are found where the standardized PBAS exceeds the standardized Depth. This finding is particularly strong for London.

The short-term volatility of trading activity variables is apparent in the second column of Figure 1. Volume and trading activity remain at low levels during the first half of the sample and a small yet stable recovery is documented for the second half of the sample period. Nevertheless, markets reacted strongly during the short sale ban period and during March-May 2010. Overall, a negative relationship is evident between quoted spread and the trading activity variables.

To conserve space, we discuss the main differences in the puts case rather than presenting all equivalent figures, Quoted spreads for puts are generally more volatile than for calls. Amsterdam quoted spreads increased in the period prior to the short sale ban and dropped sharply following the ban. London puts were generally more volatile during this period. For London, there is a drop in trading activity during March-May 2008 which coincides with the events surrounding the financial crisis (Bear Stearns was rescued on April 18, 2008). Trading

activity reached its peak in September 2008 and both volume and trading frequency became more volatile towards the end of the sample period.

4.4. Regression Results

Table 4 and 5 present regression results for equations 8 and 9 for Amsterdam and London respectively. Table 6 summarizes the expected and realised coefficient signs and the significance of the relationships that are found for both markets. Results are grouped for each liquidity and trading activity variable.

*** Insert Table 4 here***

The inventory management theory postulates that liquidity will increase with decreases in the inventory management cost, hence a negative sign is anticipated for IC and the spread measures and a positive sign for IC and asset depth. We confirm that depth increases for increasing IC levels, however our results on the spread measures show that both EPS and PBAS widen as volume increases. As in Cao and Wei (2010), the IV component of the spread is relatively less significant than the remaining spread components. We suggest that the latter findings reflect that IC captures increases in informed trading rather than inventory costs, and this is further supported by the fact that NYSE LIFFE is an order driven market in which market makers do not play a central role. We anticipate a negative coefficient for OC for EPS and PBAS as increases in transaction frequency are associated with increased economies of scale and increases in liquidity, and the findings confirm this. While increases in transaction frequency tend to narrow quoted and traded spreads, the effect on Depth is also negative, hence asset depth decreases as OC increases. This is however an anticipated outcome as increases in transaction frequency ultimately lead to fewer contracts on the order book.

OI is expected to reflect changes in informed trading and a positive sign is anticipated as traders are expected to widen their spreads due to the increased adverse selection risk. Also, regarding Depth, we expect that increases in open interest lead to increases in the number of contracts offered, hence a positive sign is expected. Overall, confirming both hypotheses above implies that if OI is a liquidity rather than an informed trading indicator, then a negative (positive) sign is expected for EPS and PBAS (Depth). However, if OI also reflects informed trading then EPS and PBAS should widen when OI increases. Tables 4 and 5, show that spreads widen as OI increases which confirms the hypothesis that OI reflects informed trading in the options market (see Jayaraman and Frye, 2001). As expected, the relationship between OI and Spread is positive and highly significant. Similarly, we anticipate that increases in open interest are positively associated with the trading activity indicators. This hypothesis is highly statistically significant for both markets apart from the frequency measure for London.

*** Insert Table 5 here***

The derivatives hedging theory postulates that increases in initial hedging cost are expected to widen spreads as investors would find it more difficult to hedge their positions in the underlying market (see Cho and Engle, 1999).[20] The results for Amsterdam calls are only marginally significant whereas mixed signs are found for London. Similarly, no clear pattern emerges for depths. For the trading activity indicators, we anticipate that increases in hedging costs will lead to a decrease in option trading activity, hence a negative sign is expected. This finding is confirmed for both Amsterdam and London calls however the signs for puts are

[20] The reverse sign is expected for puts.

mixed. Overall, we do not find evidence that the initial hedging cost is a strong determinant of option liquidity and trading activity.[21]

Kaul et al. (2004) show that the initial hedging cost is only a small proportion of the total hedging cost as investors need to constantly rebalance their positions if they want to remain hedged. As in Petrella (2006) and Engle and Neri (2010), for the hedge rebalancing cost, we have used gamma times the volatility of the underlying stock. We expect that HRC will be positively associated with EPS and PBAS. Our results show a highly significant relationship between HRC and traded and quoted spreads. For the depth indicator, the results for Amsterdam are mixed, however, the results for London show increases in asset depth with increasing HRC levels, reflecting an improvement in asset depth as hedging costs increase. In line with the depth measure results, our trading activity indicators show a highly negative relationship for Amsterdam volume and frequency and a highly positive relationship for London.

Lesmond (2005) notes that the larger firms are expected to be more liquid, hence a negative sign is expected for asset spreads and a positive sign for asset depth and the trading activity indicators. The hypothesis for spreads is confirmed for both markets for calls and puts. Similarly, the results generally support the hypothesis that depth is at higher levels for larger firms and that trading activity is concentrated in options on larger firms. Further, increases in option volatility (OV) lead to a widening of both the traded and quoted spread. This is consistent with the findings of Cho and Engle (1999) as volatility is positively correlated with underlying hedging costs. With regard to depth, our results show that while higher OV decreases asset depth for Amsterdam, the sign is reversed for London. Also, as expected, OV is positively related to trading activity. For calls, we confirm the findings of Engle and Neri

[21] It can be shown that the initial hedging cost is in fact a price level effect. Separate regression estimates when the price level variable is excluded show that the cost of setting up the hedge is positive and significant.

(2010) that spreads narrow on higher implied volatility while for puts this sign is reversed. Overall, for the trading activity indicators, higher IV levels are generally associated with decreases in trading activity.

Stoll (2000) shows that price is a proxy for risk as lower priced assets tend to carry more risk, hence, for spreads, a negative sign is hypothesized. Also, as total trade costs increase with the price level, we anticipate that increases in the price level are associated with decreases in asset depth and decreases in trading activity. Our results strongly support the latter hypotheses. In general, spreads are negatively and significantly related to the price level, a finding that also holds for depths. Pr is positively related to trading frequency for Amsterdam options, which is however anticipated as Amsterdam options trade at relatively lower prices than London.

Spreads are generally decreasing in both moneyness and maturity, a finding that is similar to Cho and Engle (1999) and Engle and Neri (2010) for the US options market. Asset depth is an increasing function of moneyness and time-to-maturity for call contracts, however the results are mixed for puts. Trading activity is generally negatively related to moneyness and time-to-maturity, however significance is not retained for all cases. Finally, the short-selling ban dummy variable shows that call spreads widen during the short-selling ban. The latter finding also holds for puts. As expected, asset depth decreased during the ban period for 3 of 4 cases. Volume decreased during the short selling ban for London, whilst it remained unchanged for Amsterdam. Similarly, SS is negatively associated with trading activity for London, but the results are mixed for Amsterdam.

*** Insert Table 6 here***

5. CONCLUSION

This paper employs three different liquidity measures (quoted and traded spreads, and depth) and two trading activity indicators (trading volume and transaction frequency), to study the time series properties of liquidity and trading activity in individual equity options for tho European exchanges. We use an extensive dataset of tick data for all individual equity options trading at NYSE LIFFE Amsterdam and London from March 2008 to December 2010.

We show that the findings of Wei and Zheng (2010) regarding the association between option volatility and liquidity in the US option markets can be explained by the derivatives hedging theory of Cho and Engle (1999). We base our results on the salient market structure of NYSE LIFFE that operates an electronic order book with market makers acting as liquidity providers. We show that in hybrid markets such as the market for single options at NYSE LIFFE, the importance of inventory management diminishes. Instead, the derivatives hedging theory can adequately explain the strong correlation of option volatility with option liquidity.

In addition, while there are two studies that offer a unique insight into the time series properties of aggregate liquidity and trading activity measures for a large sample of stock exchanges (see Chordia et al., 2001 and Lesmond, 2005), options market liquidity and trading activity are not previously well represented in the literature.

We show that widening of the traded and quoted spread is generally matched with decreases in market depth. Overall, spreads and depth vary considerably during the sample period for both exchanges, nevertheless the spread measures are generally less volatile than depth. Asset liquidity collapsed for both markets during the short sale ban in 2008 and following the market uncertainty of that period. A similar drop in liquidity for the period March-May 2010 coincides with the agreement between the International Monetary Fund and the European Union officials to supply Greece with a “rescue plan” and the credit downgrades of Spanish,

Portuguese and Greek government debt. Similarly, the time series measures of trading activity correspond to several events during the 2007-2010 financial crisis.

Overall, our regression results show that, in contrast to what is hypothesized by the inventory management theory, spreads widen on increasing levels of trading volume. We attribute this to volume capturing increases in informed trading (see Engle and Neri, 2010). Spreads widen and depths decrease with increases in transaction frequency, reflecting economies of scale in the order processing costs. Option open interest captures informed trading effects in the options market. We are unable to find clear evidence that the initial costs of hedging asset positions with the underlying assets is a strong determinant of option liquidity and trading activity. Instead, it is shown that the initial hedging cost reflects a price level effect in options. However, our results strongly support the hedge rebalancing hypothesis, hence we confirm that increases in the cost associated with constantly rebalancing hedged positions are associated with a widening of spreads.

Our results have important implications for asset pricing as we show that underlying market liquidity is a strong determinant of option spreads. The events surrounding the financial crisis are also shown to have a substantial impact on the liquidity and trading activity of European options markets.

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	Table 1: Descriptive statistics					
	Amsterdam Calls (Puts)					
	EPS	PBAS	Depth	Volume	Frequency	Price
μ	8.19 (8.76)	10.20 (11.35)	751.51 (789.87)	1391.16 (1184.10)	42.50 (35.12)	0.98 (0.83)
σ	4.95 (5.59)	5.68 (6.85)	701.08 (715.53)	2586.55 (2119.41)	48.00 (39.86)	0.80 (0.54)
|Δ% μ|	10.06 (10.60)	8.55 (9.56)	6.42 (6.54)	47.41 (47.83)	30.12 (27.18)	10.48 (9.45)
|Δ % σ|	9.59 (9.97)	7.96 (9.16)	7.55 (6.96)	52.45 (54.67)	27.60 (24.75)	10.72 (9.47)
	London Calls (Puts)					
	EPS	PBAS	Depth	Volume	Frequency	Price
μ	7.59 (7.20)	14.43 (14.60)	35.39 (35.65)	117.20 (88.77)	3.51 (3.10)	41.30 (42.40)
σ	5.83 (5.90)	7.33 (8.55)	47.30 (47.73)	411.17 (305.40)	6.97 (5.57)	50.37 (42.34)
|Δ% μ|	20.08 (22.81)	8.30 (8.96)	4.44 (4.79)	91.64 (81.80)	49.81 (45.69)	23.08 (18.30)
|Δ% σ|	17.2 (22.77)	9.12 (8.28)	5.05 (5.54)	170.75 (185.05)	58.83 (47.75)	26.09 (17.33)

EPS refers to effective percentage spread (in basis points). PBAS refers to percentage bid-ask spread (in basis points). Depth refers to half the number of contracts at ask and bid price. Volume is the total number of contracts traded and Frequency refers to the total number of trades. EPS, PBAS and Depth are aggregated to daily averages. Volume and Frequency are estimated as totals per day. Option price is the continuous option price for the nearest-to-mature, ATM contracts. Figures for put contracts are given in parentheses. μ refers to the equally-weighted average and to σ standard deviation. |Δ% μ| refers to the average value of absolute daily percentage changes and |Δ% σ| refers to the standard deviation of absolute daily percentage changes.

Table 2: Liquidity and trading activity measures by exchange and market value					
	Market Value Percentile				
	Smallest	40th	60th	80th	Largest
	Amsterdam Calls (Puts)				
EPS	8.02 (9.21)	8.88 (8.80)	8.93 (9.11)	6.80 (7.37)	6.82 (7.05)
PBAS	10.55 (12.36)	10.56 (11.44)	10.73 (11.34)	8.22 (8.75)	8.08 (8.31)
Depth	392.77 (417.78)	911.01 (943.53)	1047.93 (1096.22)	809.92 (869.77)	1536.12 (1623.51)
Volume	545.36 (406.46)	1383.27 (1098.94)	1738.32 (1721.95)	2234.06 (2401.86)	4305.43 (3225.90)
Frequency	27.74 (20.57)	38.33 (29.51)	37.12 (36.02)	75.87 (74.91)	112.30 (88.80)
Price	1.03 (0.87)	0.84 (0.83)	0.80 (0.68)	1.14 (0.83)	1.31 (0.94)
	London Calls (Puts)				
EPS	9.66 (8.74)	9.00 (8.04)	8.11 (7.89)	5.95 (5.90)	7.27 (7.04)
PBAS	18.99 (18.21)	16.63 (16.05)	14.95 (16.06)	10.75 (10.99)	12.59 (13.34)
Depth	23.09 (23.14)	35.08 (34.86)	33.00 (33.68)	23.75 (24.04)	61.75 (61.93)
Volume	50.42 (48.45)	76.95 (53.67)	67.35 (69.54)	80.85 (69.01)	245.50 (162.83)
Frequency	1.54 (1.40)	1.97 (1.70)	2.30 (2.44)	4.70 (4.38)	6.12 (4.78)
Price	15.87 (18.48)	20.09 (23.31)	47.56 (47.23)	61.48 (61.27)	40.11 (40.25)

Market Value refers to the total market capitalisation of the underlying asset. EPS refers to effective percentage spread (in basis points). PBAS refers to percentage bid-ask spread (in basis points). Depth refers to half the number of contracts at ask and bid price. Volume is the total number of contracts traded and Frequency refers to the total number of trades. EPS, PBAS and Depth are aggregated to daily averages. Volume and Frequency are estimated as totals per day. Price is the continuous option price for the nearest-to-mature, ATM contracts. Figures for put contracts are given in parentheses.

Table 3: Liquidity and trading activity measures by hedging cost percentiles					
Panel A: Initial Hedging Cost					
Percentile	Smallest	40th	60th	80th	Largest
	Amsterdam Calls (Puts)				
EPS	6.65 (8.75)	7.67 (9.16)	8.62 (8.93)	8.66 (8.51)	8.71 (8.30)
PBAS	7.67 (11.79)	9.55 (11.76)	10.66 (11.28)	10.98 (10.85)	11.16 (10.51)
Depth	719.02 (651.17)	832.64 (813.33)	881.35 (911.43)	777.9 (861.80)	631.62 (809.25)
Volume	1407.09 (868.26)	1650.58 (1142.36)	1612.18 (1368.15)	1373.09 (1450.08)	1122.66 (1348.89)
Frequency	54.48 (26.67)	49.73 (31.95)	44.70 (36.99)	38.41 (42.76)	33.36 (46.08)
Price	1.37 (0.83)	1.02 (0.78)	0.91 (0.79)	0.89 (0.83)	0.86 (0.98)
	London Calls (Puts)				
EPS	7.33 (7.29)	6.82 (7.49)	7.68 (7.23)	7.93 (6.90)	8.35 (6.85)
PBAS	14.36 (15.19)	13.11 (14.64)	14.22 (14.42)	14.78 (13.97)	15.7 (13.52)
Depth	31.90 (28.09)	35.62 (39.62)	46.86 (45.00)	34.38 (41.19)	30.57 (33.90)
Volume	91.03 (56.31)	129.53 (92.07)	185.37 (113.23)	104.42 (106.33)	86.68 (109.49)
Frequency	2.76 (2.15)	4.66 (3.02)	4.22 (3.52)	3.41 (4.04)	3.37 (4.71)
Price	47.81 (39.52)	48.39 (32.70)	41.17 (37.27)	33.69 (44.75)	30.75 (68.02)
Panel B: Hedge Rebalancing Cost					
Percentile	Smallest	40th	60th	80th	Largest
	Amsterdam Calls (Puts)				
EPS	2.67 (36.25)	4.09 (5.39)	4.86 (5.95)	6.87 (7.46)	10.38 (10.71)
PBAS	1.31 (60.55)	5.09 (7.02)	6.05 (7.57)	8.45 (9.36)	13.13 (13.70)
Depth	133.66 (91.86)	243.24 (257.71)	405.48 (437.80)	710.44 (740.61)	929.30 (967.60)
Volume	108.89 (717.00)	538.46 (508.14)	843.54 (982.26)	1458.42 (1311.38)	1573.91 (1195.64)
Frequency	0.87 (3.09)	41.94 (34.43)	51.55 (46.20)	49.82 (42.29)	35.54 (26.87)
Price	8.16 (0.46)	1.97 (1.32)	1.61 (1.22)	1.08 (0.95)	0.64 (0.60)
	London Calls (Puts)				
EPS	6.48 (6.34)	8.8 (8.00)	14.12 (13.04)	16.79 (17.34)	23.07 (19.94)
PBAS	12.17 (13.06)	16.94 (15.99)	27.56 (25.67)	31.91 (31.56)	41.24 (39.96)
Depth	20.02 (20.16)	53.68 (53.86)	130.65 (131.50)	119.25 (129.32)	87.71 (104.16)
Volume	58.92 (46.95)	199.21 (144.91)	358.54 (259.28)	202.18 (277.03)	94.74 (113.70)
Frequency	3.33 (2.90)	3.93 (3.52)	2.95 (2.35)	1.86 (3.10)	1.65 (1.91)
Price	57.72 (58.42)	16.58 (18.37)	5.27 (5.99)	4.21 (3.42)	3.37 (3.46)

EPS refers to effective percentage spread (in basis points). PBAS refers to percentage bid-ask spread (in basis points). Depth refers to half the number of contracts at ask and bid price. Volume is the total number of contracts traded and Frequency refers to the total number of trades. EPS, PBAS and Depth are aggregated to daily averages. Volume and Frequency are estimated as totals per day. Price is the continuous option price for the nearest-to-mature, ATM contracts. Figures for put contracts are given in parentheses.

	Table 4: Regression analysis: Amsterdam									
	Calls					Puts				
Dependent	(1) EPS	(2) PBAS	(3) Depth	(4) Volume	(5) Frequency	(1) EPS	(2) PBAS	(3) Depth	(4) Volume	(5) Frequency
Intercept	15.13	19.29	-136.60	513.40	23.48	13.99	19.23	-440.90	-913.00	-8.13
	(25.93)***	(29.85)***	(-3.37)***	(2.48)**	(5.08)***	(29.74)***	(32.26)***	(-7.75)***	(-4.13)***	(-2.14)**
IC	6.24E-05	1.08E-04	1.23E-02	.	.	-6.34E-05	-1.80E-05	4.38E-02	.	.
	(3.32)***	(4.85)***	(4.22)***	.	.	(-2.48)**	(-0.70)	(6.83)***	.	.
OC	-0.01	-0.02	-1.02	.	.	-0.01	-0.02	-0.20	.	.
	(-13.40)***	(-14.60)***	(-9.17)***	.	.	(-9.66)***	(-14.79)***	(-0.99)	.	.
OI	1.95E-06	2.07E-06	1.13E-03	2.37E-03	3.37E-05	3.63E-07	4.19E-07	5.99E-04	1.19E-03	1.94E-05
	(15.78)***	(14.98)***	(58.03)***	(27.00)***	(19.10)***	(2.28)**	(2.89)***	(28.71)***	(16.62)***	(13.52)***
HC	0.04	0.08	-9.07	-13.98	-0.95	-1.25E-03	-0.02	16.81	45.64	1.80
	(1.85)*	(1.81)*	(-2.47)**	(-2.12)**	(-2.11)**	(-0.07)	(-1.21)	(4.78)***	(3.85)***	(5.38)***
HRC	0.47	0.92	-31.76	-101.10	-3.42	0.45	0.83	12.59	-46.28	-0.83
	(6.46)***	(12.81)***	(-6.42)***	(-4.62)***	(-9.51)***	(5.71)***	(15.85)***	(1.81)*	(-2.44)**	(-3.58)***
MV	-0.75	-1.30	159.10	183.50	8.06	-0.28	-0.67	293.50	498.60	12.77
	(-8.82)***	(-13.27)***	(18.31)***	(4.14)***	(9.10)***	(-3.83)***	(-7.54)***	(22.00)***	(11.53)***	(15.83)***
OV	0.02	0.03	-1.39	5.73	0.22	0.02	0.02	-2.97	6.21	0.30
	(5.18)***	(7.95)***	(-4.37)***	(3.36)***	(6.29)***	(5.75)***	(6.42)***	(-10.86)***	(6.19)***	(13.99)***
IV	-0.74	-0.88	-182.40	-1182.30	-26.25	3.66	3.70	164.10	111.70	-25.49
	(-2.48)**	(-3.09)***	(-5.35)***	(-8.88)***	(-9.15)***	(8.70)***	(9.94)***	(3.61)***	(0.47)	(-8.21)***
Pr	-2.72	-3.00	-178.80	-68.39	13.55	-4.65	-5.06	-502.60	-202.20	16.32
	(-27.61)***	(-27.73)***	(-25.61)***	(-2.65)***	(11.61)***	(-28.88)***	(-33.58)***	(-34.37)***	(-5.90)***	(16.92)***
Mon	-22.23	-31.40	2684.80	-4681.00	-125.00	-13.59	-17.25	-342.10	-3312.60	5.83
	(-4.57)***	(-6.56)***	(5.59)***	(-2.17)**	(-2.57)**	(-1.80)*	(-2.81)***	(-0.57)	(-1.55)	(0.14)
Exp	-0.05	-0.06	2.54	-7.00	-0.61	-0.06	-0.09	4.92	-6.74	-0.51
	(-7.74)***	(-7.78)***	(6.07)***	(-2.99)***	(-8.83)***	(-8.38)***	(-10.58)***	(7.59)***	(-3.30)***	(-10.94)***
SS	4.01	1.42	-218.20	-454.10	3.23	2.10	-0.38	170.60	16.10	13.13
	(6.06)***	(2.31)**	(-2.72)***	(-1.49)	(0.82)	(2.91)***	(-0.64)	(2.15)**	(0.07)	(4.70)***
Adj-R^2	0.51	0.61	0.74	0.20	0.17	0.42	0.55	0.53	0.12	0.20

EPS refers to effective percentage spread. PBAS refers to percentage bid-ask spread. Depth refers to half the number of contracts at ask and bid price estimated at 10-minute intervals. Volume is the total number of contracts traded and Frequency refers to the total number of trades. IC is the inventory cost, OC refers to opportunity cost and OI refers to information HC refers to the initial hedging cost and HRC refers to hedge rebalancing cost. Pr refers to option price. MV is the log of market value of the underlying asset. OV refers to option volatility and IV refers to implied volatility. Mon and Exp refer to the average moneyness and time-to-maturity respectively per day for each contract. SS is a short selling dummy that takes the value of 1 for the duration of the short sale ban for the assets that were affected by it. T-statistics in parentheses. *, **, *** denote significance at 10%, 5% and 1% levels, respectively.

	Table 5: Regression analysis: London									
	Calls					Puts				
Dependent	(1) EPS	(2) PBAS	(3) Depth	(4) Volume	(5) Frequency	(1) EPS	(2) PBAS	(3) Depth	(4) Volume	(5) Frequency
Intercept	19.93	42.04	-2.37	-258.50	-13.17	13.16	33.20	58.41	-145.50	-10.41
	(19.09)***	(38.67)***	(-0.43)	(-4.82)***	(-10.83)***	(10.75)***	(25.63)***	(7.30)***	(-2.88)***	(-8.13)***
IC	6.63E-04	4.98E-04	1.28E-02	.	.	3.23E-04	4.81E-04	1.40E-02	.	.
	(2.79)***	(3.32)***	(6.17)***	.	.	(2.00)**	(2.91)***	(4.37)***	.	.
OC	-0.05	-0.03	-0.55	.	.	-0.05	-0.07	-0.59	.	.
	(-5.85)***	(-5.00)***	(-6.13)***	.	.	(-6.09)***	(-7.93)***	(-6.03)***	.	.
OI	1.65E-06	6.18E-06	2.41E-04	8.52E-04	9.26E-07	-9.88E-08	3.32E-06	2.87E-04	6.18E-04	1.85E-07
	(2.87)***	(10.97)***	(33.25)***	(10.37)***	(1.17)	(-0.15)	(5.53)***	(35.27)***	(8.59)***	(0.25)
HC	1.53E-05	-4.41E-05	-2.27E-03	-2.96E-03	2.99E-05	0.01	0.01	-0.09	-0.02	1.48E-03
	(0.79)	(-2.80)***	(-18.81)***	(-2.14)**	(2.36)**	(0.52)	(1.13)	(-2.26)**	(-0.12)	(0.18)
HRC	17.07	32.57	121.20	146.50	-1.35	14.55	27.51	207.90	232.40	-0.41
	(11.25)***	(21.40)***	(6.55)***	(2.67)***	(-2.08)**	(10.07)***	(17.62)***	(10.85)***	(3.34)***	(-0.33)
MV	-1.88	-4.96	3.37	73.73	4.33	-0.62	-3.23	-8.12	45.91	3.33
	(-8.87)***	(-23.02)***	(2.89)***	(5.62)***	(15.06)***	(-2.69)***	(-13.06)***	(-5.49)***	(4.15)***	(11.80)***
OV	0.01	-5.86E-04	0.05	0.17	0.02	0.01	0.01	0.04	-0.08	0.01
	(2.65)***	(-0.24)	(2.68)***	(1.14)	(5.60)***	(5.38)***	(4.27)***	(4.87)***	(-1.03)	(3.83)***
IV	-0.06	-0.25	-0.24	0.37	-0.01	1.07	1.03	-33.94	40.22	2.26
	(-1.98)**	(-7.23)***	(-2.28)**	(0.4)	(-0.36)	(2.33)**	(2.01)**	(-6.88)***	(1.77)*	(3.98)***
Pr	-0.03	-0.03	-0.10	-0.44	-0.01	-0.04	-0.04	-0.04	-0.37	-2.82E-03
	(-12.63)***	(-13.84)***	(-12.78)***	(-7.54)***	(-3.71)***	(-22.19)***	(-23.74)***	(-3.25)***	(-5.55)***	(-1.42)
Mon	-24.92	-66.02	29.21	-824.60	-8.72	13.32	16.37	-38.39	-243.40	-31.95
	(-3.59)***	(-10.05)***	(0.64)	(-1.70)*	(-0.71)	(1.59)	(1.6)	(-0.75)	(-0.60)	(-3.66)***
Exp	-0.08	-0.14	0.14	-0.09	-0.02	-0.06	-0.12	0.06	-0.34	-0.01
	(-11.07)***	(-15.34)***	(4.46)***	(-0.23)	(-2.06)**	(-7.49)***	(-12.54)***	(1.58)	(-1.34)	(-1.95)*
SS	1.51	4.15	-22.99	-71.85	-0.82	4.01	6.47	-8.86	-63.79	-1.70
	(2.29)**	(7.31)***	(-6.08)***	(-4.47)***	(-2.36)**	(4.75)***	(9.50)***	(-2.07)**	(-3.24)***	(-3.20)***
Adj-R^2	0.22	0.55	0.71	0.12	0.05	0.18	0.40	0.71	0.09	0.04

EPS refers to effective percentage spread. PBAS refers to percentage bid-ask spread. Depth refers to half the number of contracts at ask and bid price estimated at 10-minute intervals. Volume is the total number of contracts traded and Frequency refers to the total number of trades. IC is the inventory cost, OC refers to opportunity cost and OI refers to information HC refers to the initial hedging cost and HRC refers to hedge rebalancing cost. Pr refers to option price. MV is the log of market value of the underlying asset. OV refers to option volatility and IV refers to implied volatility. Mon and Exp refer to the average moneyness and time-to-maturity respectively per day for each contract. SS is a short selling dummy that takes the value of 1 for the duration of the short sale ban for the assets that were affected by it. T-statistics in parentheses. *, **, *** denote significance at 10%, 5% and 1% levels, respectively.

Table 6: Hypothesized Signs and Summary of Regression Results

	Panel A: Liquidity								Panel B: Trading Activity				
(1)	(2)	(3) EPS Call/Put		(4) PBAS Call/Put		(5)	(6) Depth Call/Put		(7)	(8) Volume Call/Put		(9) Frequency Call/Put	
Variable	Expected Sign	Amsterdam	London	Amsterdam	London	Expected Sign	Amsterdam	London	Expected Sign	Amsterdam	London	Amsterdam	London
IC	-	$+^{a}/-^{b}$	$+^{a}/+^{b}$	$+^{a}/-$	$+^{a}/+^{a}$	+	$+^{a}/+^{a}$	$+^{a}/+^{a}$	.	.	.	.	.
OC	-	$-^{a}/-^{a}$	$-^{a}/-^{a}$	$-^{a}/-^{a}$	$-^{a}/-^{a}$	-	$-^{a}/-$	$-^{a}/-^{a}$	.	.	.	.	.
OI	+	$+^{a}/+^{b}$	$+^{a}/-$	$+^{a}/+^{a}$	$+^{a}/+^{a}$	+	$+^{a}/+^{a}$	$+^{a}/+^{a}$	+	$+^{a}/+^{a}$	$+^{a}/+^{a}$	$+^{a}/+^{a}$	+/+
HC	Call/Put: +/-	$+^{c}/-$	+/+	$+^{c}/-$	$-^{a}/+$	Call/Put: -/+	$-^{b}/+^{a}$	$-^{a}/-^{b}$	-	$-^{b}/+^{a}$	$-^{b}/-$	$-^{b}/+^{a}$	$+^{b}/+$
HRC	+	$+^{a}/+^{a}$	$+^{a}/+^{a}$	$+^{a}/+^{a}$	$+^{a}/+^{a}$	.	$-^{a}/+^{c}$	$+^{a}/+^{a}$	-	$-^{a}/-^{b}$	$+^{a}/+^{a}$	$-^{a}/-^{a}$	$-^{b}/-$
MV	-	$-^{a}/-^{a}$	$-^{a}/-^{a}$	$-^{a}/-^{a}$	$-^{a}/-^{a}$	+	$+^{a}/+^{a}$	$+^{a}/-^{a}$	+	$+^{a}/+^{a}$	$+^{a}/+^{a}$	$+^{a}/+^{a}$	$+^{a}/+^{a}$
OV	+	$+^{a}/+^{a}$	$+^{a}/+^{a}$	$+^{a}/+^{a}$	$-/+^{a}$	.	$-^{a}/-^{a}$	$+^{a}/+^{a}$	+	$+^{a}/+^{a}$	+/-	$+^{a}/+^{a}$	$+^{a}/+^{a}$
IV	-	$-^{b}/+^{a}$	$-^{b}/+^{b}$	$-^{a}/-^{a}$	$-^{a}/+^{b}$	.	$-^{a}/+^{a}$	$-^{b}/-^{a}$	.	$-^{a}/+$	$+/+^{c}$	$-^{a}/-^{a}$	$-/+^{a}$
Pr	-	$-^{a}/-^{a}$	$-^{a}/-^{a}$	$-^{a}/-^{a}$	$-^{a}/-^{a}$	-	$-^{a}/-^{a}$	$-^{a}/-^{a}$	-	$-^{a}/-^{a}$	$-^{a}/-^{a}$	$+^{a}/+^{a}$	$-^{a}/-$
Mon	-	$-^{a}/-^{c}$	$-^{a}/+$	$-^{a}/-^{a}$	$-^{a}/+$	+	$+^{a}/-$	+/-	.	$-^{b}/-$	$-^{c}/-$	$-^{b}/+$	$-/-^{a}$
Exp	-	$-^{a}/-^{a}$	$-^{a}/-^{a}$	$-^{a}/-^{a}$	$-^{a}/-^{a}$	+	$+^{a}/+^{a}$	$+^{a}/+$	.	$-^{a}/-^{a}$	-/-	$-^{a}/-^{a}$	$-^{b}/-^{c}$
SS	+	$+^{a}/+^{a}$	$+^{b}/+^{a}$	$+^{b}/-$	$+^{a}/+^{a}$	-	$-^{a}/+^{b}$	$-^{a}/-^{b}$	-	-/+	$-^{a}/-^{a}$	$+/+^{a}$	$-^{b}/-^{a}$

EPS refers to effective percentage spread. PBAS refers to percentage bid-ask spread. Depth refers to half the number of contracts at ask and bid price. Volume is the total number of contracts traded and Frequency refers to the total number of trades. Sign refers to the hypothesized sign. IC is the inventory cost, OC refers to opportunity cost and OI refers to information HC refers to the initial hedging cost and HRC refers to hedge rebalancing cost. Pr refers to option price. MV is the log of market value of the underlying asset. OV refers to option volatility and IV refers to implied volatility. Mon and Exp refer to the average moneyness and time-to-maturity respectively per day for each contract. SS is a short selling dummy that takes the value of 1 for the duration of the short sale ban for the assets that were affected by it. ^{c}, ^{b}, ^{a} denote significance at 10%, 5% and 1% levels, respectively.
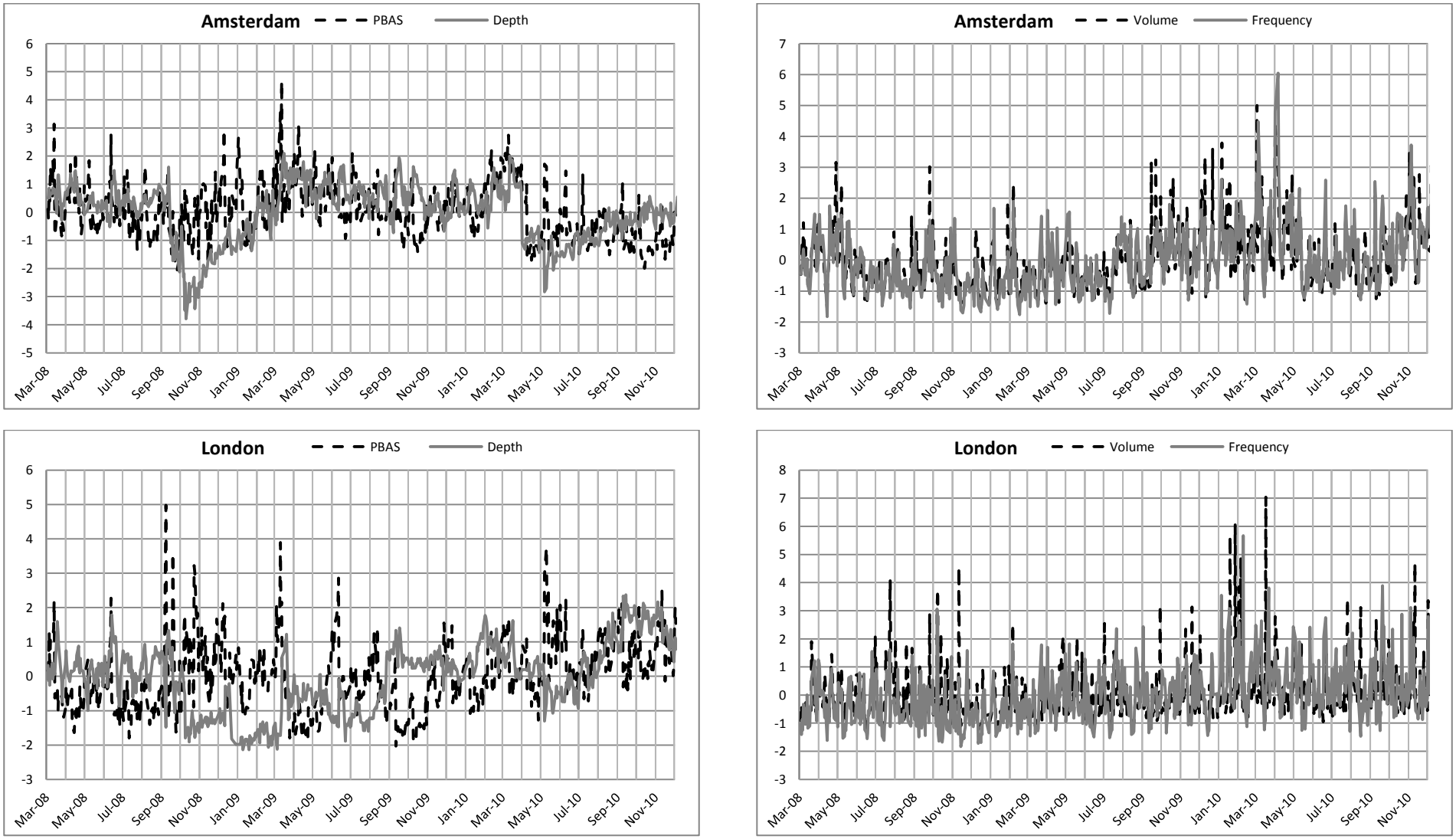
Figure 1: Time Series Liquidity and Trading Activity: Calls