Limit Order Book and Commonality in Liquidity

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Abstract:

Obtaining a unique limit order dataset provided by NYSE, we find there exits significant commonality in the liquidity provided by the NYSE limit order book. We also examine how the commonality documented above can explain the commonality in bid-ask spread, and how this commonality in limit order book is related with the liquidity commonality contributed by specialist firm. We find that the cost-to-trade and the dispersion of individual stock's limit order book co-move with the corresponding aggregate market limit order book measures. On the limit order book, there is an asymmetric relationship between individual liquidity and market liquidity on bid- and ask-side: individual stock liquidity co-moves more with the market liquidity on the same side rather than the opposite side. Furthermore, the commonality in limit order book is significantly related to commonality in bid-ask spread.

Keyword: Limit order book, Commonality, Liquidity

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1. Introduction

The market-wide co-movement of individual stock liquidity has received attention from the recent literature. Chordia, Roll and Subrahmanyam (2000) find significant co-movement between individual liquidity and market liquidity and this co-movement remains significant after controlling for volatility, volume, and price level. Huberman and Halka (2001) document the presence of a market-wide component of liquidity. Hasbrouck and Seppi (2001) also investigate the common factors in the liquidity proxies. These studies show that commonality in liquidity exists in the U.S. stock market.[1] However, the source of the commonality in liquidity is an unanswered question. A recent study by Coughernour and Saad (2004) suggests that some portion of the liquidity commonality is due to the specialists from the same specialist company. In this study, we examine the commonality of liquidity provided by another liquidity source, that is, the limit order book. Limit orders play an important role in providing liquidity in stock market (Seppi (1997), Chung et al. (1999), and Foucault et al. (2005), among others). Kang and Yeo (2007) finds that the trading strategy of limit order traders are affected by some market-level aggregate factors, such as the market return and the expected volatility implied by the option market. These studies suggest that the common determinants of the trading behavior of limit order traders on different stocks could lead to the commonality in the liquidity provided by limit order book, which will serve as a potential source of the commonality in overall liquidity observed in the stock market.

[1] These initial studies are quite meaningful and they point to a flow of research on the effects of market-wide liquidity on stock returns. Some studies (Pastor and Stambaugh (2002), Acharya and Pedersen (2004), etc) have shown that the variation in market-wide liquidity is an important factor in explaining the cross-section of stock returns while others (Amihud (2002), Bekaert, Harvey, and Lundblad (2007), etc) have shown that it can also explain the time-series of stock returns.

To be more specific, the main issues this paper addresses include: (i) Is there any commonality in liquidity provided by the NYSE limit order book? (ii) Does the stock-level liquidity provided by the bid-side of the limit order book co-moves with the market-level measures on the ask-side? (iii) What is the relationship among the commonality in limit order book, the commonality in bid-ask spread, and the liquidity co-movement contributed by specialist firm?

There have been a few studies focusing on the commonality in limit order book on small samples. For example, Kempf and Mayston (2006) examine the commonality in liquidity using limit order books of 30 equities which make up the blue-chip index DAX 30 in the Frankfurt Stock Exchange. Domowitz, Hansch and Wang (2005) investigate the commonality in limit order book of 19 stocks which consistently made up the ASX-20 index from March 2000 to December 2000. However, as far as we are aware of, there is no previous studies examining the commonality in liquidity provided by the limit order book in a large and comprehensive sample such as our sample including all the NYSE ordinary stocks. In this paper, we apply the methodology of Chordia et al (2000) on the liquidity measures complied from the NYSE OpenBook database, which contains the entire limit order books for over 1,500 NYSE-listed stocks, to examine the existence of limit order book commonality. Our results show that there is strong evidence of commonality in liquidity provided by the NYSE limit order book. For example, the change of the cost-to-trade measure of the stock-level limit order book liquidity provision displayed an average contemporaneous beta around 1.0 with associated t-statistics higher than 40. The extended quote records in the NYSE OpenBook database also allow us to decompose both individual stock liquidity and market liquidity into bid- and ask-side measures and test whether bid- and ask-side market liquidity has different influence on individual stock bid- and ask-side liquidity. We find there is an asymmetric relationship between individual liquidity and market liquidity on bid-side and ask-side of the limit order book. The stock-level liquidity provided by the bid-side of its limit order book co-moves more with the market-level liquidity provided by the same side (i.e. the bid-side) of limit order book in aggregate. Adding industry-level liquidity factor suggests that there is strong evidence of industry-level commonality in the limit order book even after controlling for the co-movement of market liquidity in limit order book documented above.

Obtaining the evidence of commonality in the NYSE limit order book, we proceed to examine whether this commonality can explain the commonality in overall liquidity, measured by the bid-ask spread, documented in the previous literature. We find that the commonality in bid-ask spread is significantly related to the commonality of limit order book cost-to-trade and dispersion measures. Our results indicate commonality in limit order book can at least partially explain the commonality in overall liquidity on the market.

This paper also examines the relationship between commonality in limit order book and the commonality contributed by specialist firm. Using bid-ask spread as the liquidity measure, we regress individual stock's liquidity on the liquidity of the specialist firm portfolio excluding the stock examined and the liquidity of the market portfolio excluding the stocks within the specialist firm portfolio. The estimated coefficients of the market liquidity and of the specialist firm liquidity are used to measure the market-level commonality in liquidity and liquidity contributed by specialist firm, respectively. Our results show some evidence of the independence between commonality in liquidity in limit order book and commonality contributed by the specialist firm.

In brief, we make the following contributions to the literature. We present the evidence of the commonality in limit order book on the NYSE, the largest stock exchanges in the world, in a large and comprehensive sample for the first time in the literature. We further show that commonality is asymmetric with regard to the bid-side and ask-side of the limit order book. Next, by showing that the limit order book commonality exists even without specialist quotes and their inventory concern and it is significantly related to commonality in bid-ask spread, our findings provide an explanation for commonality in overall liquidity on the stock market.

The rest of the paper is organized as follows. Section 2 presents the literature review. Section 3 describes our data and how we measure the liquidity provided by the limit order book. The methodology and the empirical results pertaining to the evidence of commonality are shown in section 4 while the industry commonality and the size effect are examined in section 5. Section 6 examines the relationship among the commonality in limit order book, the commonality in bid-ask spread, and the liquidity co-movement contributed by specialist firm. Section 7 concludes our paper.

2. Background

Liquidity has been a topic of microstructure for a long period of time. However, until Chordia, Roll and Subrahmanyam (2000), studies on liquidity focused only on individual securities. By assuming the existence of market liquidity, Chordia, Roll and Subrahmanyam (2000) investigate the commonality in liquidity based on 1,169 NYSE firms in 1992 and find that individual liquidity co-moves with market liquidity and this co-movement remains significant even after controlling for individual liquidity determinants such as volatility, volume and price. Huberman and Halka (2001), using the 1996 Trades and Automated Quotations (TAQ) database, examine the time-series properties of the liquidity proxies and also document the presence of a market-wide component of liquidity. However, Hasbrouck and Seppi (2001) employ the principal component analysis (PCA) and the canonical correlation analysis to investigate the common factors in the liquidity for 30 stocks making up the Dow Jones Industrial Average during 1994 and do not find conclusive evidence of common factors in the liquidity. While all the above studies examine the commonality in liquidity in on the NYSE, which is a hybrid market where both specialists and limit order traders providing liquidity, Brockman and Chung (2002) apply the market model in Chordia, Roll and Subrahmanyam (2000) to an order-driven market, the Stock Exchange of Hong Kong (SEHK) and they also find a significant relationship between individual liquidity and market liquidity. Bauer (2004) performs a Principal Component Analysis (PCA) for liquidity measures of the limit order book in the Swiss Stock Exchange, which is also a purely order-driven market, and also documents the existence of commonality in liquidity.

One common feature of the above studies is that they focus only on the best quotes when constructing the liquidity measures. Recently there is a flow of literature which measures liquidity by using information from the complete limit order book. Irvine, Benston and Kandel (2000) construct a measure of liquidity, the Cost of Round trip trade (CRT), which aggregates the status of the limit order book at any moment in time for a certain transaction size. They use data from Toronto Stock Exchange (TSE) and show that CRT has better ability to predict the subsequent activity than other liquidity measures such as effective spread constructed by using the best prices. Kang and Yeo (2006) conduct a comprehensive analysis for the NYSE limit order book and construct various measures of limit order book liquidity such as dispersion, depth and cost-to-trade. They show that the liquidity measures using information of the limit order book have more explanatory and prediction power than other liquidity measures suggested by previous studies and the limit order book provides considerable liquidity beyond the best quotes.

However, there are few studies examining the commonality in liquidity in limit order book. One exception is Kempf and Mayston (2005). They argue that the best limit prices and quantities alone are insufficient to capture the liquidity (and commonality in liquidity) of an asset because when orders are large, many price limits in the limit order book will be hit and the large market orders will walk up the limit order book. By using standard model as in Chordia, Roll and Subrahmanyam (2000) and constructing the liquidity measures based on the open limit order book of 30 equities which make up the blue-chip index DAX 30 in the Frankfurt Stock Exchange (FSE) during the period from January 2nd, 2004 to March 31st, 2004, they show that commonality in liquidity becomes stronger the deeper they look into the limit order book. Domowitz, Hansch and Wang (2005) construct a liquidity measure from the supply and demand perspective compliled from the limit order book for 19 stocks which consistently made up the ASX-20 during their sample period. They show that the co-movements in supply and demand induced by cross-sectional correlation in order types can be a source of liquidity commonality.

Although Kempf and Mayston (2005) and Domowitz, Hansch and Wang (2005) examine the commonality in liquidity using the whole limit order book, they use data from stock exchanges such as the Frankfurt Stock Exchange (FSE) and the Asutralian Stock Exchange which are order-driven markets where limit order book is displayed to all traders connected to the system and specialists play no role. It is well known that there is a considerable difference between order-driven markets and hybrid markets such as the NYSE. However, to the best our knowledge, none of the literature so far investigates the commonality in liquidity beyond the best quotes in the NYSE limit order book, primarily because only specialists can access the limit order book.

In an attempt to find why commonality in liquidity exists, Coughenour and Saad (2004) show that because of shared capital and information among specialists within a firm, stock liquidity co-moves with liquidity of other stocks handled by the same specialist firm, with magnitude increasing with the risk of providing liquidity. In other words, they show that specialists within a firm contribute to commonality in liquidity. However, Chung et al (1999) find that large portion of posted bid-ask quotes comes from the limit order book without direct participation by specialists, and the competition between traders and specialists has a significant impact on the posted bid-ask spread. Nevertheless, to our best knowledge, none of studies address the issue of whether there is commonality in the NYSE limit order book, which can be another source of commonality in liquidity on the NYSE. Furthermore, all the previous studies examine commonality in liquidity in the market-wide level and none of them ever examine bid-side and ask-side market liquidity, separately. The more important issue remaining to be addressed is if the NYSE limit order book commonality does exist, how it relates to commonality in liquidity on the NYSE and to the commonality contributed by specialist firm. This study fills the gap by investigating the above issues.

3. Data and liquidity measures

3.1 Data

The limit order book data, namely the NYSE OpenBook database, is provided by the New York Stock Exchange. It contains detailed information about the limit order book for all the securities traded on the NYSE. For each trading day, the database contains two files. The first one includes the total number of shares for each price point for each stock at the close of the operation of the OpenBook system on a specific day. The second file contains the incremental changes to the number of shares for each price point for each stock from the close of the OpenBook on that particular day to the close of the Openbook system on the next trading day. Incremental changes include activities such as limit order submission, execution, and cancellation. For every incremental change, the amount of change in the number of shares and the corresponding price point are recorded, with the exact time stamp of the change. We can treat the first file as daily data about the limit order book while the second one as intraday data. In this study, we use the first file to construct our liquidity measures and conduct our analysis. For each stock, we construct its limit order book for up to the best 100 quotes on both bid and ask sides over the daily frequency. The limit order book thus can be recorded as a vector of its best 100 limit buy order sizes and price points and its best 100 limit sell order sizes and price points for each stock on every trading day.

Stocks included in our sample are ordinary U.S. stocks listed on the NYSE, and our sample period is from January 2003 to December 2003. We exclude stocks with following characteristics:

- ADRs, units, shares of beneficial interest, companies incorporated outside U.S., Americus Trust components, close-ended funds, preferred stocks, and REITS
- The average prices are below $3 or above $999
- On average have less than five quotes on either the bid side or the ask side of their limit order books[2]

After all the filterings, our sample contains 1,376 stocks. Compared with previous studies, we have large sample size and relatively long sample period, which enable us to conduct a comprehensive analysis on commonality in liquidity in the world's most important dealer market, the NYSE.

In addition to the NYSE OpenBook database, we collect the transaction-level data from the NYSE Trades and Automated Quotations (TAQ)[3] and return and stock price data from the Center for Research in Security Prices (CRSP). In the supplementary analysis, we also use macroeconomic data from Federal Reserve Bank reports and Bloomberg.

3.2 Construction of liquidity measures

Although there is no consensus on the definition of liquidity, generally a market is said to be liquid if people can easily buy or sell a large quantity of instruments without

[2] These stocks account for less than 3% of the total sample.
[3] For the transaction data, if the trades are out of sequence, recorded before the market open or after the market close, or with special settlement conditions, they are not used in the computation of liquidity measures such as the daily spread. Quotes posted before the market open or after the market close are also discarded. The anomalous transaction records are deleted according to the following filtering rules: (i) Negative bid-ask spread; (ii) Quoted spread > $5; (iii) Proportional quoted spread > 20%; (iv) Effective spread / Quoted spread > 4.0.

causing impact on market prices and an asset is said to be liquid if the market for that asset is liquid. To be able to compare the results of this paper to those in previous studies, we construct our first three liquidity measures based on quoted spread and quoted depth from TAQ. Quoted spread is the price difference between the best offer price and the best bid price and it gives information on how much one as a liquidity demander has to pay for the liquidity to compensate the liquidity providers such as market markers and limit order traders. In this paper, we scale the quoted spread by the bid-ask midpoint to minimize the effect of different stock prices and thus get the liquidity measure of proportional quoted spread, $PQSPR_{j,t}$. Quoted depth is the volume of transactions at the best bid and offer prices necessary to move prices. We use both dollar volume and share volume to construct the quoted depth measures, $dollar_{j,t}$ and $share_{j,t}$. The quoted spread and depth measures are generated by taking average of all quoted spreads and depth reported in TAQ of all transactions within any given trading day. The larger the proportional quoted bid-ask spread, the less liquid the asset. In contrast, the larger the quoted depth measured by dollar and share volume, the more liquid the asset.

Now as the limit order book data on the NYSE are available, we also use the liquidity measures of dispersion and cost-to-trade of the limit order book, constructed by Kang and Yeo (2007), to measure the liquidity provided by the limit order book[4]. They have done a comprehensive analysis and shown that these measures have high correlation with other liquidity measures such as Amihud Illiquidity measure and Market VIX. [5]

[4] Since Kang and Yeo (2007) show that depth alone is not a good measure of liquidity in limit order book, we don't use it in this paper.

[5] Here, we only present the specific form and the main idea of the measures. For supplementary information on why and how they construct the liquidity measures for the limit order book, please read their paper.

3.2.1 Dispersion of the limit order book

Dispersion of the book conveys information on how close orders are placed to the best quotes and to each other. The dispersion of the limit order book for stock *j*, $LDisp_{j,}$ can be constructed as follows:

$$LDspr_j = \frac{1}{2}\left(\frac{\sum_{i=1}^{n} w_i^{Buy} Dst_i^{Buy}}{\sum_{i=1}^{n} w_i^{Buy}} + \frac{\sum_{i=1}^{n} w_i^{Sell} Dst_i^{Sell}}{\sum_{i=1}^{n} w_i^{Sell}} \right) \quad (1)$$

Dst is the price interval and $h \in \{Buy, Sell\}$ indicates the bid or offer side of the limit order book. w_i^h is the bid and offer size, i.e. Q_i^h in the depth measure. Two methods are used to measure Dst. The first one uses the size-weighted average interval (*SWI*), in which Dst_i^h is defined as the price interval between the i^{th} best bid or offer and its next best quote, that is, $Dst_i^{Buy} = (Bid_{i-1} - Bid_i)$ and $Dst_i^{Sell} = (Sell_i - Sell_{i-1})$. However, if *i*=1, Dst is the price interval between the best bid (offer) price and the mid-quote. The second method is the size-weighted average spread (SWS), in which Dst_i^h is the price interval between the i^{th} best quotes and the mid-quote. For both measures, the larger the dispersion measured by $LDspr_j$, the less liquid the limit order book for stock *j*.

3.2.2 Cost-to-Trade

Large market orders usually walk up or down the limit order book, which causes the discrepancy of their execution price from their intrinsic value. The larger the discrepancy, the more the trade will cost the market order trader. The measure of Cost-to-Trade takes trade size into account and captures this kind of cost by calculating the cost to buy and sell certain amount of trading volume simultaneously[6]. Let T be the total number of shares to be bought or sold, P_i^{Buy} (P_i^{Sell}) the i^{th} best bid (offer) price and Q_i^{Buy} (Q_i^{Buy}) the i^{th} best bid (offer) size. Define two indicator variables, I_k^{Buy} and I_k^{Sell}, which refer to the number of shares one can buy or sell according to the current quotes at each price point:

$$I_k^{Buy} = \begin{cases} Q_i^{Buy} & if\ T > \sum_{i=1}^{k} Q_i^{Buy} \\ (T - \sum_{i=1}^{k-1} Q_i^{Buy}) & if\ T > \sum_{i=1}^{k-1} Q_i^{Buy}\ and\ T < \sum_{i=1}^{k} Q_i^{Buy} \\ 0 & otherwise \end{cases}$$

and (2)

$$I_k^{Sell} = \begin{cases} Q_i^{Sell} & if\ T > \sum_{i=1}^{k} Q_i^{Sell} \\ (T - \sum_{i=1}^{k-1} Q_i^{Sell}) & if\ T > \sum_{i=1}^{k-1} Q_i^{Sell}\ and\ T < \sum_{i=1}^{k} Q_i^{Sell} \\ 0 & otherwise \end{cases}$$

Then assuming the true value of the stock is the midquote, the cost to trade T shares of stock j can be computed as:

$$Cost-to-Trade_j = \frac{\sum_{k=1}^{K} I_k^{Buy}(Midquote - P_k^{Buy}) + \sum_{k=1}^{K} I_k^{Sell}(P_k^{Sell} - Midquote)}{2T \times Midquote} \qquad (3)$$

For each stock in our sample, we construct the four liquidity measures. In particular, we compute the dispersion measure of the limit order book based on the best 5

[6] This measure is quite similar to the Cost of Round Trip (CRT) proposed by Benston, Irvine and Kandel (2002). The main difference is that CRT is calculated for certain dollar amount while Cost-to-Trade measure is calculated for certain number of shares to be bought or sold.

and 10 quotes on both bid and offer sides. For the cost-to-trade measure, we examine the cost to buy and sell simultaneously 1% and 2% of the average trading volume of one stock.[7] For simplicity, we report our results for the measures of proportional quoted spread from TAQ ($PQSPR_{j,t}$), the linearly declining weighted average measures of depth of limit order book ($LDW_{j,t}$), the size-weighted average interval measure of dispersion of limit order book($SWI_{j,t}$) and the cost-to-trade measure.

[Insert Table1 here.]

The sample statistics are shown in Table 1. In panel A, we show the descriptive statistics for the level measures of liquidity. We first get the time-series mean for each stock for each liquidity measure and then do the cross-sectional analysis for these mean values. Since for all the measures, their median values are smaller than their mean values, the stocks in our sample are slightly right skewed. Panel B shows the Pearson correlation between the liquidity measures. Here, we use the percentage change measures of liquidity to offer information on how good our constructed liquidity measures are. A few patterns are observed. First, liquidity measures constructed using less quotes and more quotes (or for smaller trades and larger trades for the cost-to-trade measure) are moderately correlated. The correlation coefficient is from 0.58 to 0.61. Unreported results also show that liquidity measures within in one category are highly correlated. For example, the correlation between limit order book dispersion measured size-weighted average interval (*SWI*) and measured by size-weighted average spread (*SWS*), using best five quotes is as high as 0.946. Second, all the liquidity measures are positively and

[7] We also construct the dispersion measures based on the best 15 quotes and the cost to buy and sell 3% of the average trading volume. However, construction of these measures reduces our sample size dramatically. Hence, we do not use these measures.

significantly correlated, which is as we expect. All together, the results of the correlation analysis indicate that our constructed measures are able to capture the liquidity in the limit order book.

4. Empirical evidence of commonality in liquidity

Currently, there are two methods to examine commonality in liquidity. One is the market model in Chordia, Roll and Subrahmanyam (2000). The other is the principal component analysis (PCA) method in Hasbrouck and Seppi (2001). In this paper, we follow the spirit of the first method. Although it ex ante assumes the existence of market liquidity, it, compared to the PCA method, has the advantage that we can add some control variables in the regression. Specifically, the specification of the market model is as follows:

$$L_{j,t} = \alpha_j + \beta_j^1 L_{M,j,t} + \beta_j^2 L_{M,j,t-1} + \beta_j^3 L_{M,j,t+1} + \gamma_j^1 R_{M,t} + \gamma_j^2 R_{M,t-1} + \gamma_j^3 R_{M,t+1} + \delta_j V_{j,t} + \varepsilon_{j,t} \quad (4)$$

where

$L_{j,t}$ = the liquidity measure for stock *j* on day *t*;

$L_{M,j,t}$ = the market liquidity measure for stock *j* on day *t*;

$L_{M,j,t-1}$ = the market liquidity measure for stock *j* on day *t-1*;

$L_{M,j,t+1}$ = the market liquidity measure for stock *j* on day *t+1*;

$R_{M,t}$, $R_{M,t-1}$, $R_{M,t+1}$ = market return on day *t*, *t-1*, and *t+1*, respectively;

$V_{j,t}$ = volatility of stock *j* on day *t*; and

$\varepsilon_{j,t}$ = error term.

The lag and lead market liquidity variable are added to the regression because of the possible non-concurrent adjustment of commonality. Concurrent, lag and lead market return and concurrent stock volatility are used to capture other factors that have an influence on the co-movement of individual stock liquidity with market liquidity. Consistent with Chordia, Roll and Subrahmanyam (2000), we use the percentage change of each liquidity measure in the regression since our concern is the co-movement of individual stock liquidity with market liquidity. Furthermore, level measures usually lead to higher R^2, which is one of measures of commonality. Hence, the percentage change measures are more robust when examining the commonality. Concurrent, lag and lead market return use level measures and concurrent volatility uses percentage measures. Market liquidity for stock j, $L_{M,j,t}$, is the equal-weighted average liquidity of all stocks other than stock j to exclude the possible mechanical co-movement of stock j's liquidity with market liquidity. We first do a time-series analysis using regression (4) for each stock then take the cross-sectional mean of the estimated coefficients to get our final estimated coefficients.

When examining the magnitude of commonality in liquidity, some studies (Chordia, Roll and Subrahmanyam (2000); Huberman and Halka (2001); etc) rely more on the estimated βs while others (e.g., Kempf and Mayston (2006)) use the value of adjusted R^2 of the market model. In our study, when examining the existence of commonality, we rely more on the significance of estimated βs.[8] On the other hand, when we compare the magnitude of commonality, we use adjusted R^2 since it is able to

[8] Ideally, the value of β should be close to 1.

capture how much of the variation of individual stock liquidity can be explained by the variation of market liquidity.

In this section, we first report the results using best quotes data from TAQ, then the results of commonality in the limit order book and lastly results of commonality of the limit order book when the bid-side and ask-side individual stock liquidity as wekk as market liquidity are separated.

4.1 Commonality at best quotes from TAQ

To compare our results with those of Chordia, Roll and Subrahmanyam(2000) and to examine the contribution of specialist and limit order traders to commonality in liquidity in the later analysis, we first run regression (4) using the best quotes data from TAQ. The results are shown in the first column of Table 2.

[Insert Table 2 here.]

Since most of the estimated coefficients for the lag and lead market liquidity measures as well as for the control variables are not significant, here and hereafter, we only report the estimated coefficients for the concurrent market liquidity and the sum of the estimated coefficients for the concurrent, lag and lead market liquidity. For the bid-ask spread measure, average estimated coefficients for concurrent market liquidity is 0.970 with a t-statistic of 61.9, indicating strong evidence of commonality in liquidity. Using quoted depth leads to similar results. To give some information on the distribution of βs, we also report the percentage of positive and positive and significant βs. When bid-ask spread measure is used, over 97% of βs in the regression for individual stocks are positive and over 77% of them are positive and significant. This again shows strong evidence of commonality in liquidity. The average adjusted R^2 is 6.6%, which is higher than the corresponding value of 1.7% in Chordia, Roll and Subrahmanyam (2000). As they use the data in 1992, this difference may due to the time-series variation of commonality.[9] Taken together, we have shown strong evidence of commonality in bid-ask spread.

4.2 Commonality in the limit order book

Column 2 to 5 in Table 2 shows the results of commonality in the limit order book. There is ample evidence of commonality in liquidity in the limit order book where specialists play no role. The average estimated coefficients for the concurrent market liquidity are all statistically significant for the two limit order book liquidity measures. Two important patterns are observed from the adjusted R^2. First, to the extent that the values of the adjusted R^2 for the regressions using limit order book liquidity measures are comparable to the value of adjusted R^2 in the first column, we also have strong evidence of commonality in the limit order book. Second, as we use liquidity measures constructed by more quotes in the limit order book, we usually get lower values of adjusted R^2. The indication is that submission of limit orders away from the best is not a very common behavior and can not contribute much to the commonality in liquidity. This result is contrary to what Kempf and Mayston (2005) report, i.e., commonality in liquidity is stronger as we go deeper into the limit order book. Our speculation for the discrepancy is the difference in the microstructure of the two stock exchanges, as for one stock exchange the limit order book is open to the investors while for the other it isn't.

[9] We also run the regression using level liquidity measures. The average adjusted R^2 for bid-ask spread and quoted spread measures are 36.4% and 5.5%, respectively, which shows that using level measures lead to stronger evidence of commonality.

4.3 Commonality in the limit order book when bid-side and ask-side market liquidity are separated

We decompose the market liquidity into bid-side and ask-side market liquidity in order to examine which side's commonality contributes more on the aggregated commonality. In other words, there may be an asymmetric relationship between the individual stock liquidity and the bid-side and ask-side market liquidity.[10] In this part we replace the market liquidity, $L_{M,j,t}$, in regression (4) by bid-side market liquidity, $L_{B,j,t}$, and ask-side market liquidity, $L_{A,j,t}$. The same is done for their lag and lead variables. Computation of $L_{B,j,t}$ and $L_{A,j,t}$ is the same as that of $L_{M,j,t}$ except that we are using the stocks on the bid-side and ask-side separately. For the left hand side variable in this case, we also differentiate whether the individual stock is on the bid-side or on the ask-side. All the control variables are same as in regression (4). In order to better understand the commonality when separating the bid-side and ask-side individual stock liquidity as well as market liquidity, we run the following three regressions for each stock and for individual stock liquidity on bid-side and ask-side separately[11]:

$$L_{j,t} = \alpha_j + \beta_j^1 L_{B,j,t} + \beta_j^2 L_{B,j,t-1} + \beta_j^3 L_{B,j,t+1} + \gamma_j^1 L_{A,j,t} + \gamma_j^2 L_{A,j,t-1} + \gamma_j^3 L_{A,j,t+1} + \varepsilon_{j,t} \qquad (5)$$

$$L_{j,t} = \alpha_j + \beta_j^1 L_{B,j,t} + \beta_j^2 L_{B,j,t-1} + \beta_j^3 L_{B,j,t+1} + \varepsilon_{j,t} \qquad (6)$$

$$L_{j,t} = \alpha_j + \beta_j^1 L_{A,j,t} + \beta_j^2 L_{A,j,t-1} + \beta_j^3 L_{A,j,t+1} + \varepsilon_{j,t} \qquad (7)$$

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[10] Kempf and Mayston (2006) also examine the possible asymmetric relationship between the individual stock liquidity and the bid-side and ask-side market liquidity but their method is different from ours. What they have done is to differentiate whether the left hand side variable in equation (4) is on the bid-side or ask-side and therefore run the regression separately for bid-side and ask-side individual stock liquidity.

[11] Control variables are ignored for simplicity.

The results of regressing bid-side (ask side) individual stock liquidity on the bid-side and ask-side market liquidity are reported in Panel A, Table 3. For simplicity and to be more conservative, we just show the results using the best ten quotes to construct the dispersion of limit order book and the cost to buy and sell simultaneously 2% of the average trading volume to construct the cost-to-trade measures.

[Insert Table 3 here.]

When the individual liquidity is on bid-side (ask-side) of the limit order book, the estimated coefficients of concurrent market liquidity on the bid-side (ask-side) are strongly significant while those on the ask-side (bid-side) are still statistically significant but small in magnitude. For example, when the dependent variable is individual stock's bid-side liquidity, the estimated coefficient for the concurrent bid-side market liquidity is 0.896 with t-statistics of 35.05, while the estimated coefficient for the concurrent ask-side market liquidity is 0.141 with t-statistics of 5.83. This may indicate individual stock liquidity co-moves more with its own-side market liquidity. However, the above results may also be due to the possible high correlation between the bid-side and the ask-side market liquidity. Unreported results show that when we use level liquidity measures, the correlation coefficient between bid-side and ask-side market liquidity can be as high as 0.917. When percentage change liquidity measures are used, the correlation coefficients decrease but remain relatively high. Therefore, we proceed to run regression (6) and (7) as they only include market liquidity on one side of the limit order book. We report the results in Panel B, Table 3. When bid-side (ask-side) individual stock liquidity is regressed on bid-side (ask-side) market liquidity, the estimated coefficient for the concurrent same side market liquidity is highly significant. On the other hand, when bid-side (ask-side) individual stock liquidity is regressed on ask-side (bid-side) market liquidity, the estimated coefficient for the other side concurrent market liquidity is also very significant but, in most cases, smaller in magnitude than that for the same side market liquidity. These results show that the relatively small and not strongly significant estimated coefficients in regression (5) are indeed due to the high correlation between bid-side and ask-side market liquidity. However, the values of adjusted R^2 in the regression of bid-side (ask-side) individual liquidity on its own side market liquidity are higher than those in the regression of bid-side (ask-side) individual liquidity on market liquidity on the other side of the limit order book, showing evidence that individual stock liquidity co-moves more with market liquidity on its own side of the limit order book. Overall, the results are consistent with the intuition that when common factors affect the limit buy (sell) order submissions in the market, they will have more effects on the limit buy (sell) order submissions for individual stock. The results that bid-side (ask-side) market liquidity also has effects on ask-side (bid-side) individual stock liquidity can be explained as follows. The effects of common factors on bid-side (ask-side) market liquidity will first affect bid-side (ask-side) individual stock liquidity. But, as Parlour (1998) shows, both sides of the limit order book affect traders' decision to submit a limit order or market order and therefore affect the liquidity of the book. Hence, the effects of common factors will also affect the individual stock liquidity on ask-side (bid-side) of its limit order book. However, these effects are indirect so their effects on the other side of limit order book liquidity are smaller than those on the same side of the book for individual stock.

5. Industry commonality and size effect

5.1 Industry commonality

It is possible that the common factors in the market are industry wide and they may have more effects on firms within one industry rather than cross industries. If this is true, there may be an industry wide commonality and this industry commonality will drive our results of market wide commonality in liquidity. To address this issue, we construct an industry liquidity measure using the same method constructing the market liquidity. Then we regress individual stock liquidity on both market liquidity and industry liquidity measures leaving control variables same as before. Ignoring the control variables, the specific form of this regression is as follows:

$$L_{j,t} = \alpha_j + \beta_j^1 L_{M,j,t} + \beta_j^2 L_{M,j,t-1} + \beta_j^3 L_{M,j,t+1} + \gamma_j^1 L_{I,j,t} + \gamma_j^2 L_{I,j,t-1} + \gamma_j^3 L_{I,j,t+1} + \varepsilon_{j,t} \quad (8)$$

Industry liquidity for stock *j* at time *t*, $L_{I,j,t}$, is the equal-weighted average of liquidity of all stocks within that industry excluding stock *j*'s liquidity measure. And when market liquidity for stock *j*, $L_{M,j,t}$, is constructed, in this case, all stocks within the industry to which stock *j* belongs are excluded to control for the correlation between market liquidity and industry liquidity.

[Insert Table 4 here.]

Table 4 shows the results of equation (8). Both the estimated coefficients of market liquidity and industry liquidity for all liquidity measures are significant. On the one hand, these results show that there is strong evidence of common factors affecting individual stock liquidity within industry, with the estimated coefficient for the concurrent industry liquidity ranging from 0.189 (t-statistics $\approx$11.5) to 0.244 (t-statistics

≈ 18.0). On the other hand, market wide commonality in liquidity still exists even after controlling for common factors within industry, which indicates that many common factors are cross industries and our evidence of commonality in liquidity in limit order book is not driven by industry wide commonality. Chordia, Roll and Subrahmanyam (2000) imply that one possible reason for the existence of industry commonality in liquidity on the NYSE is that inventory risks are more industry-specific. Our evidence of industry commonality in liquidity using limit order book liquidity measures shows that common factors affecting commonality within industry, a possible source of industry commonality in liquidity on the NYSE, can also be factors with no relationship with inventory-based risks of specialists.

We also examine the industry commonality when bid-side and ask-side market liquidity are separated. In this case, industry commonality is also decomposed into bid-side and ask-side liquidity. Unreported results show that when bid-side (ask-side) individual stock liquidity measures are regressed on bid-side (ask-side) market and industry liquidity measures, estimates of concurrent industry liquidity measures are all significant. But this is not the case when they are regressed on ask-side (bid-side) market and industry liquidity measures where some of estimates are insignificant and all of the estimates are small in magnitude. Again, when bid-side (ask-side) individual liquidity measures are regressed on both sides of market and industry liquidity measures, only estimates of coefficients for industry liquidity on their own side are consistently significant and their magnitudes are also relatively large. But the estimated coefficients for concurrent market liquidity are still significant in all the case. These results show that market wide commonality in liquidity in limit order book still exists even after controlling for common factors within industry in the case where bid-side and ask-side liquidity measures are examined separately. In addition, they also indicate that there is also an asymmetric relationship between individual stock liquidity and industry liquidity on the bid-side and ask-side.

5.2 Size effect

Chordia, Roll and Subrahmanyam(2000) show that large firms have more commonality in liquidity and they speculate it is because of the greater prevalence of institutional herd trading in larger firms. On the other hand, using data from the Stock Exchange of Hong Kong, Brockman and Chung (2002) do not find a positive relationship between firm size and commonality in liquidity. We also examine the size effect in commonality in limit order book. Specifically, we sort the slope coefficients in regression (4) into 5 groups based on firm's market value which is the multiple of stock price and number of shares outstanding on December 31, 2002. The mean estimated coefficients for the market liquidity for each quintile are reported in Table 5.

[Insert Table 5 here.]

It is quite apparent that there is a size effect here. If we look at the adjusted R-square, large firms usually have higher R-squares, meaning that large firms' liquidity, whether from the overall market or from their limit order books, usually co-moves more with market liquidity than small firms. We also examine the size effect for the joint bid-side and ask-side market liquidity and the separated bid-side and ask-side market liquidity. Unreported results show that there is a clear size effect: larger firms usually have higher commonality in limit order book. Our speculation for this size effect is that institutional herding behavior in terms of limit order submissions is also more severe for large firms.

6. Overall liquidity commonality relations test

6.1 The relationship between commonality in limit order book and commonality in liquidity in the stock market

One of our main motivations in this paper is to investigate whether limit order book commonality can explain the well documented commonality in liquidity in the stock market. To achieve this goal, we should relate one to the other. Beta and R-square from regression (4) are used to measure the commonality in liquidity. Specifically, we measure the commonality in liquidity in the stock market by using the beta and R-square from equation (4) when bid-ask spread and quoted depth are used to measure liquidity. To get the commonality measures for limit order book, we use beta (estimated coefficient for the market liquidity) and R-square from equation (4) when limit order book liquidity measures are used. To investigate whether commonality in limit order book is a source of commonality in stock market, we regress the commonality measures in the stock market on limit order book commonality measures:

$$CL_j = \alpha_j + \lambda_j CL\_LOB_j + \varepsilon_j \qquad (9)$$

Where

CL_j = the commonality in liquidity measure for stock *j*;

CL_LOB_j = the limit order book commonality measure for stock *j*;

ε_j = error term.

As you note, this is a cross-sectional regression as commonality in liquidity measures are regressed on limit order book commonality measures for each stock during the whole sample period. When we use beta to measure commonality, both estimated coefficient for the concurrent market liquidity and the sum of the estimated coefficients for the concurrent, lag and lead market liquidity are used. R-square is transformed by taking natural log of R-square divided by one minus R-square. The significance of λ_j will suggest that commonality in liquidity be able to explain, at least statistically, commonality in liquidity in the stock market.

[Insert Table 6 here.]

The regression results of equation (9) are shown in Table 6. For simplicity, we only report the results where quoted spread is used to construct the commonality in liquidity measure. We obtain similar results when quoted depth is used. The results show strong evidence of the ability of commonality in limit order book in explaining the commonality in liquidity. For example, when we use dispersion of limit order book constructed by best 5 quotes as a liquidity measure and use beta as a liquidity commonality measure, the correlation between commonality in limit order book and commonality in liquidity on the NYSE is as high as 0.314 with t-statistics of 11.6. The results also show that as we use more quotes and larger trades to construct the limit order book liquidity measures, commonality in limit order book contributes less to the commonality in liquidity on the NYSE. This makes sense since orders away from the best quotes in limit order book are less likely to be filled and therefore, less likely to co-move with the market liquidity on the NYSE.

6.2 The relationship between commonality in limit order book and commonality contributed by specialist firm

Coughernour and Saad (2004) argue that, due to shared capital and information among specialists within a firm, stock liquidity will co-move with the liquidity of other stocks handled by the same specialists firm. In their paper, they first sort stocks according to the specialist firm and use the mean of all other stocks in the specialist firm except the stock examined to measure specialist firm liquidity. Market liquidity is measured by the mean of the all other stocks except those handled by the specialist firm of interest. The evidence that liquidity co-variation with both the market and specialist portfolios is positive and significant indicates that specialist firm plays an important role in explaining the existence of commonality in liquidity. In this paper we also intend to investigate the relationship between commonality in limit order book and commonality contributed by specialist firm. The purpose of doing this test is to show whether commonality in limit order book is orthogonal to commonality contributed by specialist firm and therefore become another source of commonality in liquidity on the NYSE.

This analysis involves two steps. First, we replicate Table 5 in Coughernour and Saad (2004) to get the measure of market-level commonality in liquidity and the commonality contributed by specialist firm. Specifically, in each day, we form specialist firm portfolios by sorting the stocks into groups within which stocks are handled by the same specialist firm. To minimize the source of variation, the stock examined is excluded from the specialist firm portfolio. We also form market portfolios by including all other stocks which do not belong to the specialist firm portfolio. The liquidity measures of the specialist firm portfolios and of the market portfolios are obtained by taking the mean of the liquidity measures of all stocks within the specialist firm portfolios and the market portfolios. Here, we use bid-ask spread as the only liquidity measure to capture the commonality in liquidity on the NYSE. Lastly, we run a regression as follows: individual's bid-ask spread is regressed on average of bid-ask spreads for all the stocks other than stock j within the specialist firm portfolio and on the average of bid-ask spreads for all the stocks other than those belonging to the specialist firm portfolio:

$$\begin{aligned} Spread_{j,t} = \alpha_j &+ \eta_j^1 Spread_{SF,j,t} + \eta_j^2 Spread_{SF,j,t-1} + \eta_j^3 Spread_{SF,j,t+1} + \\ &\mu_j^1 Spread_{M,j,t} + \mu_j^2 Spread_{M,j,t-1} + \mu_j^3 Spread_{M,j,t+1} + \\ &\gamma_j^1 R_{M,t} + \gamma_j^2 R_{M,t-1} + \gamma_j^3 R_{M,t+1} + \delta_j V_{j,t} + \varepsilon_{j,t} \end{aligned} \quad (9)$$

where

$Spread_{j,t}$ = bid-ask spread for stock *j* on day *t*;

$Spread_{\_SF,j,t}$ = the average of bid-ask spreads for all the stocks other than stock *j* within the specialist firm portfolio on day *t*;

$Spread_{\_M,j,t}$ = the average of bid-ask spreads for all the stocks other than those belonging to the specialist firm portfolio of which stock *j* is a member on day *t*;

All the other variables are defined in the same way as before.

We are interest in η_j^1 and μ_j^1 in regression (9) as they can be interpreted as the measure of commonality contributed by specialist firm and of commonality in liquidity on the NYSE, respectively.

In the second step, we regress η_j^1 and μ_j^1 in regression (9) on the measure of liquidity commonality in limit order book, which is the estimated coefficient of market liquidity in regression (4) using limit order book liquidity measures. To be more specific, the regression specification is as follows:

$$Market\_beta_j = \alpha_j + \phi_j LOB\_beta_j + \varepsilon_j \quad (10)$$

and

$$Specialist\_beta_j = \alpha_j + \omega_j LOB\_beta_j + \varepsilon_j \quad (11)$$

where $Market\_beta_j$ is μ_j^1, the estimated coefficient of concurrent market liquidity in regression (9); $Specialist\_beta_j$ is η_j^1, the estimated coefficient of concurrent specialist firm liquidity; and LOB_beta_j is the estimated coefficient of concurrent market liquidity in regression (4) using limit order book liquidity measures. If commonality in limit order book is orthogonal to commonality contributed by specialist firm, we expect that ϕ_j in regression (10) is statistically significant but ω_j in regression (11) is statistically not different from zero.

[Insert Table 7 here.]

Table 7 reports the results for regression (10) and (11). All the estimated coefficients in regression (10) are statistically significant, suggesting that commonality in limit order book contributed to the commonality in liquidity on the NYSE after commonality contributed by specialist has been deducted. But the significance of estimated coefficient in regression (11) depends on which limit order book liquidity measure we are using. When cost-to-trade is used, it is marginally significant or insignificant but when dispersion measure is used, it is significant. We also use the sum of μ_j^1, μ_j^2 and μ_j^3 as well as the sum of η_j^1, η_j^2 and η_j^3 in regression (9), termed as 'Market_sumbeta' and 'Specialist_sumbeta' in Table (7), as the dependent variable to run regression on the sum of estimated coefficients for concurrent, lag and lead market liquidity in regression (4). In this case, most of the estimated coefficients in regression (11) are insignificant. In summary, we find some, but not very strong, evidence that commonality in liquidity in limit order book is orthogonal to commonality in liquidity contributed by specialist firm.

6.3 A robustness check: the effect of macroeconomic factors

While the existence of commonality in liquidity is well documented in the literature, the underlying factors leading to this phenomenon are still not deeply investigated. Most of the studies in this area focus on the sources of market liquidity rather than thoses of liquidity commonality. Chordia, Roll, and Subrahmanyam (2001) construct time-series indices of market-wide liquidity measures for the period from 1988 to 1998 and document that daily changes in market liquidity are affected by macroeconomic factors such as equity market returns, short-term interest rates and default spread. Chordia, Sarkar, and Subrahmanyam (2003) find that liquidity in stock markets and bond markets co-move and that monetary loosening and unexpected decreases in the Federal Funds rate affect the market liquidity. They also show that money flows, in the form of bank reserves and mutual fund investments, account for part of the commonality in stock and bond market liquidity. Fujimoto (2004) examines the macroeconomic sources of time-series variation in the US stock market liquidity over the period from 1965 through 2001 and provides evidence macroeconomic fundamentals are significant determinants of liquidity and their effects are stronger prior to the mid 1980's. However, during the latter half of the sample, i.e., from 1984 to 2001, aggregate liquidity is less responsive and more resilient to macroeconomic shocks. Qin (2006) investigates whether macroeconomic factors induce commonality in liquidity for stocks in the emerging markets. She includes GDP, CPI, investment style and other variables such as market return and volatility as the macroeconomic factors. By regressing commonality measures on these macroeconomic factors, she finds supportive evidence for the relation between commonality in liquidity and macroeconomic factors.

In this section, we examine the effect of macroeconomic factors on liquidity commonality using a different approach, that is, we investigate the issue of commonality after controlling for the macro factors. Consistent with the previous studies, we consider three macro factors: one-month T-bill rate, yield spread between 2-year AA and BBB corporate bond and a January dummy, which takes one if it is in January and zero otherwise. The data of one-month T-bill rate and the yield spread are from Federal Reserve Bank reports and Bloomberg, respectively. Since the correlation between one-month T-bill rate and the yield spread is as high as 0.70, we examine them separately but each of them is used together with the Jan dummy.

We summarize our unreported results as follows: (1) most of the coefficients for the Jan dummy are not statistically significant but most of the coefficients for the spread yield and the one-month T-bill rate are significant; (2) our previous obtained results regarding the existence of commonality in limit order book and the relationship among commonality in limit order book, commonality in liquidity in the stock market and commonality contributed by specialist firm still hold even after we control for the macro factors; and (3) adding the macro-level factors does not improve the adjusted R^2 significantly. Therefore, these results indicate that macroeconomic factors do not seem to have large effects on the existence of commonality in liquidity in either the stock market or the limit order book although they may have effects on individual stock liquidity and aggregate liquidity, as previous studies suggested. One limitation of our analysis here is that our data only cover one year which may be too short to show the whole picture of effects of macroeconomic factors on liquidity commonality.

7. Conclusion

In this study, we use the NYSE OpenBook database covering over 1,500 stocks in 2003 to study the following questions: (i) Is there any commonality in liquidity provided by the NYSE limit order book? (ii) Does the stock-level liquidity provided by the bid-side of the limit order book co-moves with the market-level measures on the ask-side? (iii) What is the relationship among the commonality in limit order book, the commonality in bid-ask spread, and the liquidity co-movement contributed by specialist firm? To our best knowledge, this is the first time to use this dataset to examine the above issues. By using limit order book measures constructed by Kang and Yeo (2006), we show that there is strong evidence of commonality in liquidity on the NYSE limit order book. After we decompose individual stock liquidity as well as market liquidity into bid-side and ask-side liquidity measures, our results show that there is an asymmetric relationship between individual stock liquidity and market liquidity on the bid-side and ask-side of the limit order book. Individual stock liquidity co-moves more with market liquidity on its own side in the limit order book although market liquidity on the other side also has some effects on it. We also find strong evidence of industry commonality and a positive relationship between firm size and commonality in limit order book.

Moreover, by regressing commonality in liquidity on the NYSE on commonality in limit order book, we find strong evidence that commonality in limit order book is able to explain the variation in commonality on the NYSE. Coughernour and Saad (2004) show that specialist firm contribute to the commonality in liquidity on the NYSE. When examining the relationship between these two sources of commonality, we find supportive evidence that commonality in limit order book is independent to commonality in liquidity contributed by specialist firm. Overall, our findings contribute to the literature by showing the existence of commonality in limit order book, which, other than commonality suggested by Coughernour and Saad (2004), is another source of commonality in liquidity on the NYSE.

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Table 1: Sample Statistics

The sample stocks include all the US ordinary stocks listed on NYSE from January 2003 to December 2003. 'Bid-Ask Spread' stands for proportional quoted spread for stock *j* and is defined as the price difference between the best ask price and best bid price divided by the bid-ask midpoint. '1 Percent' ('2 Percent') of 'Limit Order Book Cost-to-trade' measures the round-trip trade cost to simultaneously buy and sell 1% (2%) of its average trading volume against the limit order book. 'Limit Order Book Dispersion' is defined as $[(\sum_{i=1}^{n} w_i^{Buy} Dst_i^{Buy} / \sum_{i=1}^{n} w_i^{Buy}) + (\sum_{i=1}^{n} w_i^{Sell} Dst_i^{Sell} / \sum_{i=1}^{n} w_i^{Sell})]/2$, where $Dst_i^{Buy} = (Bid_{i-1} - Bid_i)$ ($Dst_i^{Sell} = (Sell_i - Sell_{i-1})$) is the price interval on the bid (offer) side of the limit order book and w_i^{Buy} (w_i^{Sell}) is the bid (offer) size. 'Best 5 Quotes' ('Best 10 Quotes') means that n equals 5 (10). We first get the time-series mean for each stock for each liquidity measure and then obtain the cross-sectional mean and median of these time series mean values.
In panel A, we report the level measures of liquidity for the descriptive statistics while in panel 8, we report the percentage measures of liquidity defined as $(L_{j,t} - L_{j,t-1})/L_{j,t-1}$, where $L_{j,t}$ stands for liquidity measures of stock *j* on day *t*, to show the correlation.

Panel A: Descriptive Statistics for Level Measures of Liquidity

		Total		Bid-side		Ask-side	
		Mean	**Median**	**Mean**	**Median**	**Mean**	**Median**
Bid-Ask Spread (from TAQ)	Proportional Quoted Spread (%)	0.18%	0.12%				
Limit Order Book Cost-to-Trade	1 Percent (%)	1.93%	1.71%	1.02%	0.89%	0.93%	0.78%
	2 Percent (%)	3.50%	3.13%	1.83%	1.59%	1.86%	1.51%
Limit Order Book Dispersion	Best 5 Quotes (cents)	6.13	4.01	6.09	3.97	6.16	4.03
	Best 10 Quotes (cents)	11.83	8.56	12.07	8.25	11.58	8.42

Panel B: The Pearson Correlation between The Liquidity Measures

		Bid-Ask Spread (from TAQ)	Limit Order Book Cost-to-Trade		Limit Order Book Dispersion	
		Proportional Quoted Spread	1 Percent	2 Percent	Best 5 Quotes	Best 10 Quotes
Bid-Ask Spread (from TAQ)	Proportional Quoted Spread	1.00	0.24	0.15	0.21	0.12
Limit Order Book Cost-to-Trade	1 Percent		1.00	0.58	0.49	0.41
	2 Percent			1.00	0.32	0.32
Limit Order Book Dispersion	Best 5 Quotes				1.00	0.61
	Best 10 Quotes					1.00

Table 2: Market-level Commonality in Liquidity

The regression specification is as follows:

$$L_{j,t} = \alpha_j + \beta_j^1 L_{M,j,t} + \beta_j^2 L_{M,j,t-1} + \beta_j^3 L_{M,j,t+1} + \gamma_j^1 R_{M,t} + \gamma_j^2 R_{M,t-1} + \gamma_j^3 R_{M,t+1} + \delta_j V_{j,t} + \varepsilon_{j,t}$$

Daily percentage changes in individual stock *j*'s liquidity are regressed in time series on daily percentage changes in market liquidity which is an equal-weighted average of liquidity of all stocks excluding stock *j*. Percentage changes in lag and lead market liquidity, level measures of concurrent, lag and lead market return and percentage measures of stock *j*'s volatility defined as square of its daily return, are control variables. All the liquidity measures are defined as in Panel A, Table 1.

Cross-sectional averages of time series slope coefficients are reported with t-statistics in parentheses. We take the cross-sectional average using slope coefficients within their 1st and 99th percentile. 'Concurrent', refer to the same day of market liquidity relative to the individual stock's trading day. 'Mean' ('Median') stands for the mean (median) values of slope coefficient for the market liquidity for trading day *t*. '% positive' stands for the percentage of positive slope coefficient and '% positive significant' refers to the percentage of positive and significant slope coefficients. We identify slope coefficients with t-statistics greater than 1.645 (the 5% critical level in a one-tailed test) as significant. 'Sum' is the sum of concurrent, lag and lead slope coefficients. 'Mean' ('Median') below sum is the mean (median) of the sum of concurrent, lag and lead slope coefficients. 'Adjusted R^2' is the cross-sectional mean of the Adjusted R^2s in regression for individual stock after truncating them by using 1 percentile. Estimated coefficient for lag and lead market liquidity, concurrent, lag and lead market return and concurrent volatility are not reported for simplicity.

	Bid-Ask Spread	**Limit Order Book Cost-to-trade**		**Limit Order Book Dispersion**	
	Proportional Quoted Spread	1 Percent	2 Percent	Best 5 Quotes	Best 10 Quotes
Concurrent					
Mean	0.970	1.051	0.981	1.044	1.106
(t-statistics)	*(61.90)*	*(59.23)*	*(45.15)*	*(60.59)*	*(71.01)*
Median	0.947	0.991	0.949	0.958	1.074
% positive	97.1%	98.2%	91.9%	100.0%	100.0%
% positive significant	77.4%	81.9%	57.1%	93.1%	94.3%
Sum					
Mean	1.034	1.068	0.994	1.070	1.144
Median	1.006	0.979	0.972	0.993	1.109
Adjusted R^2	6.61%	6.09%	2.97%	17.05%	11.01%

Table 3: Bid-side and Ask-side Limit Order Book Commonality in Liquidity

Bid-side (Ask-side) liquidity measure for stock *j* is regressed on the bid-side and/or ask-side market liquidity measure.

Panel A uses the following regression specification:

$$L_{j,t} = \alpha_j + \beta_j^1 L_{B,j,t} + \beta_j^2 L_{B,j,t-1} + \beta_j^3 L_{B,j,t+1} + \gamma_j^1 L_{A,j,t} + \gamma_j^2 L_{A,j,t-1} + \gamma_j^3 L_{A,j,t+1} + \varepsilon_{j,t}$$

where $L_{B,j,t}$ ($L_{A,j,t}$) refers to bid-side (ask-side) market liquidity for stock *j* on trading day *t* which is an equal-weighted average of bid-side (ask-side) liquidity of all stocks excluding stock *j*. Stock *j*'s bid-side (ask-side) liquidity measures are regressed on concurrent, lag and lead bid-side market liquidity and concurrent, lag and lead ask-side market liquidity measures.

In Panel B, the first three columns and the third three columns are based on the regression:

$$L_{j,t} = \alpha_j + \beta_j^1 L_{B,j,t} + \beta_j^2 L_{B,j,t-1} + \beta_j^3 L_{B,j,t+1} + \varepsilon_{j,t}$$

Stock *j*'s bid-side (ask-side) liquidity measures are regressed on concurrent, lag and lead bid-side market liquidity.
The second three columns and the fourth three columns are based on the regression:

$$L_{j,t} = \alpha_j + \beta_j^1 L_{A,j,t} + \beta_j^2 L_{A,j,t-1} + \beta_j^3 L_{A,j,t+1} + \varepsilon_{j,t}$$

Stock *j*'s bid-side (ask-side) liquidity measures are regressed on concurrent, lag and lead ask-side market liquidity.

The liquidity measures are same as defined in Panel A, Table 1 and control variable are same as defined in Table 2. 'Bid-side' ('Ask-side') on the top refers to individual stock *j*'s bid-side(ask-side) liquidity in its limit order book while 'Bid-side'('Ask-side') on the left stands for bid-side (ask-side) market liquidity. 'Concurrent', 'Mean', 'Median', '% positive', '% positive significant', 'Sum' and 'Adjusted R^2' are same as defined in Table 2 except that they are for one-side market liquidity now. We only report results for the '2 percent' limit order book cost-to-trade measure meaning simultaneously buying and selling 2% of its average trading volume against the limit order book, and for the limit order book dispersion measure constructed by the best 10 quotes. Estimated coefficients for lag and lead bid-side or ask-side market liquidity and for other control variables are ignored for simplicity.

Panel A: Joint Bid-side and Ask-side Limit Order Book Commonality in Liquidity

			Dependent Variable = Individual Stock Liquidity Measures			
			Bid Side		**Ask Side**	
			Limit Order Book Cost-to-Trade	Limit Order Book Dispersion	Limit Order Book Cost-to-Trade	Limit Order Book Dispersion
Market Liquidity Measures	**Bid Side**	**Concurrent**				
		Mean	0.896	1.100	0.141	0.108
		(t-statistics)	*(35.05)*	*(49.13)*	*(5.83)*	*(5.77)*
		Median	0.894	1.025	0.118	0.091
		% positive	87.1%	96.4%	55.5%	58.1%
		% positive significant	38.2%	55.7%	7.8%	7.6%
		Sum				
		Mean	0.882	1.023	0.207	0.134
		Median	0.838	0.918	0.153	0.114
	Ask Side	**Concurrent**				
		Mean	0.122	0.085	0.889	1.001
		(t-statistics)	*(6.10)*	*(4.58)*	*(38.15)*	*(49.07)*
		Median	0.117	0.079	0.881	0.94
		% positive	58.9%	56.3%	88.3%	95.3%
		% positive significant	6.3%	10.2%	43.5%	61.5%
		Sum				
		Mean	0.136	0.208	0.906	1.017
		Median	0.130	0.234	0.909	0.946
		Adjusted R^2	2.91%	7.95%	4.17%	7.86%

Panel B: Separate Bid-side and Ask-side Limit Order Book Commonality in Liquidity

			Dependent Variable = Individual Stock Liquidity Measures							
			Bid Side				Ask Side			
			Limit Order Book Cost-to-Trade	Limit Order Book Dispersion	Limit Order Book Cost-to-Trade	Limit Order Book Dispersion	Limit Order Book Cost-to-Trade	Limit Order Book Dispersion	Limit Order Book Cost-to-Trade	Limit Order Book Dispersion
Market Liquidity Measures	**Bid Side**	**Concurrent**								
		Mean	0.959	1.172			0.607	1.008		
		(t-statistics)	*(41.35)*	*(62.08)*			*(27.97)*	*(60.46)*		
		Median	0.920	1.073			0.583	0.977		
		% positive	90.8%	100.0%			80.3%	97.8%		
		% positive significant	47.4%	86.0%			26.3%	81.3%		
		Sum								
		Mean	0.970	1.191			0.790	1.099		
		Median	0.909	1.086			0.734	1.039		
		Adjusted R^2	2.49%	7.66%			2.43%	5.52%		
	Ask Side	**Concurrent**								
		Mean			0.486	0.874			0.946	0.874
		(t-statistics)			*(26.65)*	*(53.08)*			*(45.29)*	*(53.08)*
		Median			0.466	0.806			0.953	0.896
		% positive			80.4%	97.9%			91.9%	97.9%
		% positive significant			22.9%	75.9%			53.9%	75.9%
		Sum								
		Mean			0.624	1.016			1.004	1.016
		Median			0.633	0.953			1.013	0.953
		Adjusted R^2			1.43%	5.64%			3.99%	5.64%

Table 4: Market-level and Industry-level Commonality in Liquidity

Stock j's liquidity measures are regressed on both market liquidity and industry liquidity. The regression specification is as follows:

$$L_{j,t} = \alpha_j + \beta_j^1 L_{M,j,t} + \beta_j^2 L_{M,j,t-1} + \beta_j^3 L_{M,j,t+1} + \gamma_j^1 L_{I,j,t} + \gamma_j^2 L_{I,j,t-1} + \gamma_j^3 L_{I,j,t+1} + \varepsilon_{j,t}$$

where $L_{I,j,t}$ is the industry liquidity for stock *j* at time *t*, which is the equal-weighted average of liquidity of all stocks within that industry excluding stock *j*'s liquidity measure; $L_{M,j,t}$ is the market liquidity for stock *j* at time *t* which is the equal-weighted average of all stocks' liquidity excluding stocks within the industry to which stock j belongs. We group stocks into industries using Fama-French 17 industries standard. All the other variables are defined in a same way as before.

		Dependent Variable = Individual Stock Liquidity Measures				
		Bid-Ask Spread	**Limit Order Book Cost-to-Trade**		**Limit Order Book Dispersion**	
		Proportional Quoted Spread	1 Percent	2 Percent	Best 5 Quotes	Best 10 Quotes
Market Liquidity Measures	**Concurrent**					
	Mean	0.715	0.833	0.785	0.850	0.907
	(t-statistics)	*(36.22)*	*(32.63)*	*(26.93)*	*(40.55)*	*(37.72)*
	Median	0.691	0.757	0.792	0.770	0.843
	% positive	88.0%	88.2%	82.8%	92.2%	90.4%
	% positive significant	42.5%	39.6%	29.5%	60.0%	48.6%
	Sum					
	Mean	0.739	0.852	0.766	0.850	0.977
	Median	0.734	0.744	0.792	0.776	0.907
Industry Liquidity Measures	**Concurrent**					
	Mean	0.244	0.216	0.192	0.189	0.197
	(t-statistics)	*(18.02)*	*(11.27)*	*(8.95)*	*(11.48)*	*(10.20)*
	Median	0.211	0.171	0.141	0.108	0.151
	% positive	71.9%	64.0%	60.9%	63.9%	63.3%
	% positive significant	14.5%	12.4%	8.0%	13.2%	12.6%
	Sum					
	Mean	0.281	0.209	0.215	0.212	0.165
	Median	0.232	0.194	0.138	0.118	0.142
	Adjusted R^2	6.86%	6.51%	3.28%	17.37%	11.26%

Table 5: Commonality in Liquidity by Size Quintile

We sort the slope coefficients in regression (4) into 5 groups based on firm's market value which is the multiple of stock price and number of shares outstanding on December 31, 2002. The sample size reduces to 1,371 since 5 stocks were first listed within 2003. 'Mean' is the mean of the sum of concurrent, lag and lead slope coefficients of market liquidity with t-statistics shown in parenthesis. All the other variables are same as defined before.

			Size Quintile(Individual Stock Liquidity Measures)				
			Smallest (N=274)	**2 (N=274)**	**3 (N=274)**	**4 (N=274)**	**Largest (N=275)**
Bid-Ask Spread	**Proportional Quoted Spread**	Mean	0.981	1.249	1.111	1.010	0.882
		(t-statistics)	*(13.88)*	*(19.54)*	*(18.69)*	*(19.51)*	*(13.66)*
		Median	0.953	1.259	1.117	1.010	0.760
		Adjusted R^2	5.24%	6.41%	6.84%	7.25%	7.36%
Limit Order Book Cost-to-Trade	**1 Percent**	Mean	1.120	1.188	1.176	1.105	0.752
		(t-statistics)	*(15.63)*	*(17.92)*	*(20.25)*	*(22.93)*	*(12.23)*
		Median	1.070	1.130	1.031	1.111	0.737
		Adjusted R^2	4.62%	5.20%	5.90%	7.30%	7.49%
	2 Percent	Mean	1.102	1.237	1.174	0.888	0.555
		(t-statistics)	*(11.65)*	*(14.50)*	*(12.56)*	*(10.80)*	*(5.81)*
		Median	1.119	1.256	1.108	0.893	0.509
		Adjusted R^2	2.77%	2.98%	3.19%	3.28%	2.63%
Limit Order Book Dispersion	**Best 5 Quotes**	Mean	0.880	1.317	1.315	1.104	0.742
		(t-statistics)	*(17.77)*	*(25.93)*	*(29.39)*	*(31.17)*	*(32.55)*
		Median	0.780	1.254	1.279	1.017	0.718
		Adjusted R^2	6.43%	15.91%	19.20%	22.12%	21.78%
	Best 10 Quotes	Mean	0.888	1.205	1.307	1.341	0.999
		(t-statistics)	*(21.26)*	*(26.92)*	*(29.42)*	*(30.29)*	*(28.28)*
		Median	0.806	1.202	1.318	1.310	0.937
		Adjusted R^2	5.09%	9.23%	11.36%	13.71%	15.82%

Table 6: Relation between Bid-Ask Spread Commonality and Limit Order Book Commonality

The commonality in liquidity using bid-ask spread as liquidity measure is regressed on the commonality in liquidity using limit order book liquidity measures. The regression specification is as follows:

$$CL_j = \alpha_j + \lambda_j CL\_LOB_j + \varepsilon_j$$

where CL_j is the commonality in liquidity measure for stock *j* when we use bid-ask spread to measure liquidity and CL_LOB_j is the limit order book commonality measure for stock *j*;

'Beta' is the coefficient of concurrent market liquidity in regression (4) using bid-ask spread to measure liquidity. 'Sum_beta' is the sum of coefficients of concurrent, lad and lead market liquidity in regression (4) using bid-ask spread to measure liquidity. 'R-square' is the natural log of R-square divided by one minus R-square for regression (4) using bid-ask spread to measure liquidity. 'Beta', 'Sum_beta' and 'R-square' are regressed on the corresponding measures of liquidity commonality in limit order book. '1 Percent' ('2 Percent') refers to the estimated coefficient for the liquidity commonality in limit order book when we use measures of the round-trip trade cost to simultaneously buy and sell 1% (2%) of its average trading volume against the limit order book. "Best 5 Quotes' ('Best 10 Quotes') stands for the estimated coefficient for the liquidity commonality in limit order book when we use best 5 (10) quotes to measure the limit order book dispersion.

		Dependent Variable = Commonality in Liquidity Using Bid-Ask Spread		
		Beta	**Sum_beta**	**R-square**
Commonality in Liquidity Using Limit Order Book Cost-to-Trade	**1 Percent**	0.238	0.164	0.218
	(t-statistics)	*(8.82)*	*(5.45)*	*(6.79)*
	Adjusted R^2	7.08%	2.82%	4.32%
	2 Percent	0.133	0.066	0.126
	(t-statistics)	*(5.89)*	*(3.14)*	*(3.67)*
	Adjusted R^2	3.29%	0.96%	1.30%
Commonality in Liquidity Using Limit Order Book Dispersion	**Best 5 Quotes**	0.314	0.4010	0.230
	(t-statistics)	*(11.61)*	*(10.38)*	*(9.07)*
	Adjusted R^2	11.65%	9.54%	7.45%
	Best 10 Quotes	0.219	0.264	0.250
	(t-statistics)	*(7.05)*	*(6.32)*	*(8.01)*
	Adjusted R^2	4.64%	3.77%	5.91%

Table 7: Relation between Commonality in Limit Order Book and Commonality Contributed by Specialists

Market-level commonality in liquidity or commonality contributed by specialist is regressed on limit order book commonality in liquidity.

$$\begin{aligned} Spread_{j,t} = {} & \alpha_j + \eta_j^1 Spread_{SF,j,t} + \eta_j^2 Spread_{SF,j,t-1} + \eta_j^3 Spread_{SF,j,t+1} + \\ & \mu_j^1 Spread_{M,j,t} + \mu_j^2 Spread_{M,j,t-1} + \mu_j^3 Spread_{M,j,t+1} + \\ & \gamma_j^1 R_{M,t} + \gamma_j^2 R_{M,t-1} + \gamma_j^3 R_{M,t+1} + \delta_j V_{j,t} + \varepsilon_{j,t} \end{aligned} \tag{9}$$

where $Spread_{j,t}$ is bid-ask spread for stock *j* on day *t*; $Spread\_{SF,j,t}$ is the average of bid-ask spreads for all the stocks other than stock *j* within the specialist firm portfolio on day *t*; $Spread\_{M,j,t}$ is the average of bid-ask spreads for all the stocks other than those belonging to the specialist firm portfolio of which stock *j* is a member on day *t*.

Results in Table 7 are based on the following regression

$$Market\_beta_j = \alpha_j + \phi_j LOB\_beta_j + \varepsilon_j \tag{10}$$

or

$$Specialist\_beta_j = \alpha_j + \omega_j LOB\_beta_j + \varepsilon_j \tag{11}$$

where $Market\_beta_j$ is μ_j^1 , the estimated coefficient of concurrent market liquidity in regression (9); $Specialist\_beta_j$ is η_j^1, the estimated coefficient of concurrent specialist firm liquidity; and LOB_beta_j is the estimated coefficient of concurrent market liquidity in regression (4) using limit order book liquidity measures.

'Market_sumbeta' ('Specialist_sumbeta') is the sum of the estimated coefficients of the concurrent, lag and lead of market (specialist firm) liquidity. '1 Percent' ('2 Percent') refers to the estimated coefficient for the concurrent market liquidity in regression (4) when we use measures of the round-trip trade cost to simultaneously buy and sell 1% (2%) of its average trading volume against the limit order book. "Best 5 Quotes' ('Best 10 Quotes') stands for the estimated coefficient for the concurrent market liquidity when we use best 5 (10) quotes to measure the limit order book dispersion. Note that when we use 'Market-sumbeta' or 'Specialist_sumbeta' as dependent variable, the independent variables are also the sum of the estimated coefficients of the concurrent, lag and lead market liquidity in regression (4) using limit order book liquidity measures.

		Dependent Variable = Commonality in Liquidity Using Bid-Ask Spread			
		Market_ beta	**Specialist_ beta**	**Market_ sumbeta**	**Specialist_ sumbeta**
Commonality in Liquidity Using Limit Order Book Cost-to-Trade	**1 Percent**	0.192	0.065	0.113	0.04
	(t-statistics)	(5.04)	(1.96)	(2.29)	(0.89)
	Adjusted R^2	2.33%	0.28%	0.41%	0.00%
	2 Percent	0.122	0.002	0.086	-0.017
	(t-statistics)	(3.93)	(0.08)	(2.58)	(-0.56)
	Adjusted R^2	1.39%	0.00%	0.55%	0.00%
Commonality in Liquidity Using Limit Order Book Dispersion	**Best 5 Quotes**	0.208	0.131	0.228	0.188
	(t-statistics)	(5.17)	(3.77)	(3.35)	(3.04)
	Adjusted R^2	2.45%	1.28%	0.99%	0.80%
	Best 10 Quotes	0.167	0.077	0.151	0.122
	(t-statistics)	(3.77)	(2.01)	(2.17)	(1.92)
	Adjusted R^2	1.28%	0.30%	0.36%	0.26%