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Limit Order Book and Commonality in Liquidity

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Abstract

We show that the liquidity provided by an individual stock's limit order book comoves significantly with the market aggregate limit order book liquidity. A closer look at the inside and outside liquidity provided by different parts of limit order book suggests that inside liquidity is mainly influenced by market volatility, while idiosyncratic volatility has a larger impact on outside liquidity. Hence, limit order book inside liquidity exhibits higher commonality than outside liquidity. We also show that the comovement between the stock-level and market-aggregate limit order book liquidity measures is related to the commonality in the overall stock market liquidity.

Keywords: limit order book, commonality, liquidity

JEL Classification: G19

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1. Introduction

Liquidity is more than just an attribute that belongs to a single asset. There is an extensive body of research that examines the comovement between individual stock liquidity and market-wide liquidity, exemplified by the works of Chordia, Roll and Subrahmanyam (2000), Huberman and Halka (2001), and others. Recent studies, such as Brockman and Chung (2002), Bauer (2004), and Karolyi, Lee and Van Dijk (2012), also find evidence of liquidity commonality in international markets. All these liquidity commonality studies suggest that liquidity means not only the trading cost of an individual stock but also a potential systematic risk factor that carries important implications for expected returns in the stock market.[1] In most of these studies, the liquidity measures are based on the best bid and ask quotes, such as the quoted or effective spread and the average depth of the best quotes.

Some other recent studies focus on the liquidity provided by a particular group of market makers, that is, limit order traders. Limit orders play a vital role in providing liquidity in the stock market. Chung, Van Ness and Van Ness (1999) find that, on the NYSE, 75% of all quotes have at least one side originating from limit orders. Foucault, Kadan and Kandel (2005) show that the patience of limit order traders is an important determinant of liquidity supply in the stock market. Kang and Yeo (2009) find that the trading behavior of limit order traders is determined by market-level aggregate factors, such as market return and volatility. Since these factors also are the common determinants of stock market liquidity, it suggests that there should be commonality in the limit order traders' behavior, which is reflected in the limit order book, and this could be related to the commonality in the overall stock market liquidity.

We first examine whether there is any comovement in the liquidity provided by the limit order book, or to put it into simple words, the limit order book commonality. There have been a few studies focusing on commonality in the limit order book using small samples. For example, Domowitz, Hansch and Wang (2005) study the commonality in the limit order book of 19 stocks which consistently belong to the ASX-20 index in the Australian market. Kempf and Mayston (2008) examine commonality in liquidity using limit order books of 30 stocks in the blue-chip DAX30 index on the Frankfurt Stock Exchange. More recently, Corwin and Lipson (2010) examine the order flow data of 100 NYSE-listed stocks and find that the common factors in the order flow can explain a fraction of the variation in limit order book liquidity measures.

However, as far as we are aware, there are no previous studies examining the limit order book commonality in a large and comprehensive sample—for example,

[1] Pastor and Stambaugh (2003) and Acharya and Pedersen (2005) find that the sensitivity of stock returns to market liquidity can explain the cross-sectional variation of expected returns. Other papers (e.g., Amihud, 2002; Bekaert, Harvey and Lundblad, 2007) show that changes in market liquidity can predict the time series variation of stock market returns. Kamara, Lou and Sadka (2008) find that the cross-sectional variation of liquidity commonality has increased over the period 1963–2005, and therefore reduced the capability of diversification by holding large-cap liquid stocks.

a sample covering all of the NYSE ordinary stocks. Obtaining a data set from the NYSE OpenBook system, which contains the limit order book information for all of the stocks listed on the NYSE, we apply the methodology of Chordia, Roll and Subrahmanyam (2000) to the liquidity measures compiled from the limit order book of more than 1,000 NYSE-listed ordinary stocks in the calendar year 2003. Our results show strong evidence of limit order book commonality. In the market-factor regression model, the comovement beta coefficient of individual stock's limit order book liquidity measure on the market aggregate limit order book liquidity measure displays an average value around 1.0, with associated t-statistics higher than 20.

Furthermore, the uniqueness of our limit order book data allows us to examine the difference between the commonality of inside liquidity and that of outside liquidity provided by the limit order book. In our empirical test, we define inside liquidity as the dispersion measure based on the first and the second best limit orders, and outside liquidity as the dispersion measure based on the sixth to the tenth best limit orders. Previous studies, such as Chordia, Roll and Subrahmanyam (2000) and Coughenour and Saad (2004), essentially test the commonality of inside liquidity, since their liquidity measures are based on the best bid and ask quotes in the market (e.g., the bid-ask spread). On the NYSE, the specialists, who are more likely to be the providers of inside liquidity, need to maintain the continuity of stock prices. Their market-making behavior can be affected by market state variables, such as market returns and market volatility, as shown in Comerton-Forde, Hendershott, Jones, Moulton and Seasholes (2010). Therefore, we should expect high commonality of inside liquidity.

On the other hand, probably because of the lack of data to establish an appropriate empirical measure, outside liquidity remains an unexplored dimension of liquidity and very little is known about its attributes and commonality pattern. For example, is there more or less commonality in outside liquidity compared to inside liquidity? Our study sheds light on this question. We find that limit order book outside liquidity measures display substantially lower commonality than inside liquidity measures. In the market-factor commonality regression model, the average adjusted R^2 is 31.64% for inside liquidity, while it is only 6.80% for outside liquidity.

Additional analyses on how the market- and stock-level volatility influence the inside and outside liquidity differently provide more insights into why the levels of commonality of these two liquidity dimensions differ from each other. We find that market volatility mainly affects the limit order book inside liquidity, while idiosyncratic volatility is more likely to have an impact on the outside liquidity. Since it is the inside liquidity that is more likely to be subject to the influence of market factors such as market volatility, it is natural for it to exhibit higher commonality than outside liquidity.

Given the importance of liquidity commonality, the source of such commonality is still an unanswered question. Some portion of liquidity commonality comes from specialist portfolio. For example, Coughenour and Saad (2004) suggest that the specialist portfolio can explain about one-eighth of the stock-level liquidity change. Liu (2009) shows that the trading quality of inactive stocks benefits from being in the same specialist portfolio with high-volume stocks. Harford and Kaul (2005) find that the order imbalance comovement generated by index trading contributes to the commonality in liquidity, but mostly for Standard and Poor (S&P) 500 constituents. In our paper, we examine whether the limit order book commonality can explain the previously documented commonality in overall stock market liquidity, measured by the bid-ask spread. We find that the overall stock market liquidity commonality measures, such as the beta and R^2 estimates from the bid-ask spread "market-model" regression, are significantly correlated with the same commonality measures from the limit order book "market-model" regression. We also show some portion of an individual stock's bid-ask spread time series variation is explained by its comovement with market aggregate limit order book liquidity measures.

In brief, we make the following contributions to the literature. We present the evidence of limit order book commonality on the NYSE, one of the largest stock exchanges in the world, using a comprehensive sample for the first time in the research. More importantly, we explore the commonality of inside liquidity versus outside liquidity, provided by the limit order book, and find that inside liquidity exhibits much stronger commonality than outside liquidity. Next, by showing that individual stock's bid-ask spread comoves with the market aggregate limit order book measures, our study provides an explanation for the commonality in the overall stock market liquidity.

2. Data and methodology

2.1. Data description

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 of all the common stocks traded on the NYSE. For each trading day, the database consists of two files. The first one includes the 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 submissions, executions, and cancellations. For every incremental change, the amount of change (in the number of shares) and the corresponding price point are recorded, along with the exact time stamp of the change. For order submissions (order executions or cancellations), the number of shares in the order is recorded as a positive (negative) change at the corresponding price point in the limit order book.

There are typically more than 5 million records of incremental changes in the limit order book per day. In our one-year sample period, our limit order book data include a total of more than 1 billion observations. We first construct the limit order book for up to the best 100 quotes on both bid and ask sides at five-minute intervals from 9:30 a.m. (the market opening) to 4 p.m. (the market close). Then we compute the limit order book liquidity measures at the daily frequency, based on the five-minute interval intraday limit order book snapshots constructed above.

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 American depository receipts, units, shares of beneficial interest, companies incorporated outside the United States, Americus Trust components, close-ended funds, preferred stocks, and real estate investment trusts. We require the average price of each of the stocks in our sample to be between \$3 and \$999. We also require that, for a stock to be included in our sample, there should be at least five quotes on either the bid side or the ask side of its limit order book. After this filtering, our sample contains 1,024 stocks. Compared with previous studies, we have a much larger sample size, which enables us to conduct a comprehensive analysis on commonality in liquidity in one of the world's most important equity markets. In addition to the NYSE OpenBook database, we obtain the transaction-level data from the NYSE Trades and Automated Quotations (TAQ)[2] and return and stock price data from the CRSP.

2.2. Construction of liquidity measures

In our paper, we use multiple liquidity measures computed from the TAQ and the NYSE OpenBook database introduced earlier. First, we construct the proportional and dollar-quoted spread measures from the TAQ database. The dollar-quoted spread is defined as the price difference between the best ask price and the best bid price, and the proportional quoted spread is the dollar-quoted spread scaled by the midquote. These spread measures provide information on how much the trader, who demands immediacy in his trades, has to compensate the liquidity providers, such as the market maker and limit order traders. In our paper, we interpret these spread measures as a proxy of the overall liquidity in the stock market.

Next, we focus on the liquidity provided by limit order book. We construct two limit order book liquidity measures, the dispersion and cost-to-trade of limit order book. The limit order book dispersion measure conveys information on how clustered or dispersed the limit order book is, by measuring how close the limit orders are placed to each other. The dispersion of the limit order book for stock i, $LDispersion_i$, is constructed as follows

$$LDispersion_i = \frac{1}{2}\left(\frac{\sum_{j=1}^{n} w_j^{Buy} Dst_j^{Buy}}{\sum_{j=1}^{n} w_j^{Buy}} + \frac{\sum_{j=1}^{n} w_j^{Sell} Dst_j^{Sell}}{\sum_{j=1}^{n} w_j^{Sell}} \right). \tag{1}$$

[2] 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 also are 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.

Dst_j is the price interval between the jth best bid or offer and its next best quote. Hence, $Dst_j^{Buy} = (Bid_{j-1} - Bid_j)$ and $Dst_j^{Sell} = (Ask_j - Ask_{j-1})$. If $j = 1$, Dst_j is the price interval between the best bid or offer price and the midquote. We weight Dst_j by the size of limit orders: the weight, w_j, is the size of the corresponding bid or offer limit order. The weight is normalized by dividing each weight by the sum of all of the weights. Larger dispersion in the limit order book suggests that it provides a lower amount of liquidity. In other words, when there is high competition among the limit order traders, they undercut each other to gain price priority. As a result, the *LDispersion* measure tends to be small and implies high liquidity in the market.

Another limit order book liquidity measure used in our paper is the cost-to-trade, which can be thought of as an enhanced depth measure for the limit order book. Imagine there is a large market order (or a series of market orders in the same direction). The market buy (sell) order will first be executed against the limit sell (buy) order at the best offer (bid) quote. When the volume of the market order is larger than the best offer (bid) size, the remainder of the unexecuted market order will be executed against the limit orders queuing at the next best offer (bid) quote. As the large market order walks up or down the limit order book, its execution price will deviate from its intrinsic value. The larger the deviation, the more it will cost the market-order trader. Hence, we design the cost-to-trade measure as the cost to buy and sell a certain amount of stock simultaneously.[3] We denote T as the total number of shares to be bought and sold, $P_j^{Buy}(P_j^{Sell})$, as the jth best bid (offer) price, and $Q_j^{Buy}(Q_j^{Sell})$ as the jth best bid (offer) size. We further define an indicator variable, I_k^h, where $h \in \{Buy, Sell\}$, which refers to the number of shares bought or sold, respectively at each price point:

$$I_k^h = \begin{cases} Q_k^h & \text{if } T > \sum_{j=1}^{k} Q_j^h \\ \left(T - \sum_{j=1}^{k-1} Q_j^h\right) & \text{if } T > \sum_{j=1}^{k-1} Q_j^h \quad \text{and} \quad T < \sum_{j=1}^{k} Q_j^h \\ 0 & \text{otherwise.} \end{cases} \qquad (2)$$

The (round-trip) cost-to-trade measure for stock i is defined as the ratio of the trading cost calculated above to the fair value of the trade, which is estimated by multiplying the total number of shares to be traded by the midquote price level

[3] This measure is similar to the cost of round trip (CRT) measure proposed by Benston, Irvine and Kandel (2002). The main difference is that CRT is calculated for a certain dollar amount, while the cost-to-trade measure is calculated for a certain number of shares to be bought or sold.

$$\textit{Cost-to-Trade}_i = \frac{\sum_{k=1}^{k} I_k^{Buy}\left(Midquote - P_k^{Buy}\right) + \sum_{k=1}^{k} I_k^{Sell}\left(P_k^{Sell} - Midquote\right)}{2T \times Midquote}. \tag{3}$$

For each stock in our sample, we construct the following liquidity measures: the limit order book dispersion measure based on the best five and ten quotes; the cost-to-trade measure based on the cost to buy and sell simultaneously 1% and 2% of the average daily trading volume of the stock; and the proportional and dollar-quoted spreads. The summary statistics are shown in Table 1. We first obtain the time series average of our liquidity measures for each stock during the sample period and then present the cross-sectional statistics for these stock-level values. The limit order book dispersion measure based on the best five (ten) quotes is 6.15 (11.84) cents, which implies that the limit order book becomes more dispersed as one moves away from the best quote. The cost-to-trade based on the cost to buy and sell 1% (2%) of the average daily trading volume is 1.94% (3.50%), which suggests that it is more costly to execute a large market order (or a series of market orders in the same direction) against the limit order book.

We report the mean and median of the limit order book liquidity measures in size quintile portfolios, which are sorted based on sample stock's market capitalization at the beginning of our sample period. As we would expect, small stocks have larger limit order book dispersion and higher cost-to-trade than large stocks. In other words, there tends to be less liquidity in the limit order book of small stocks. We also notice that our limit order book liquidity measures exhibit concavity to some extent. For example, the cost-to-trade based on 2% of the average daily trading volume is slightly less than two times of the cost-to-trade based on 1% of the daily volume. This observation implies that the fixed component of trading cost, which can be thought of as the spread investors pay when they trade a small amount, remains significant in our sample period.

3. Empirical evidence of the limit order book commonality

We follow the method of Chordia, Roll and Subrahmanyam (2000) to examine whether there is any commonality in liquidity provided by the limit order book. We conduct a regression of the daily percent changes in the stock-level limit order book liquidity measures on the daily percent changes in the market-level average of such measures. More precisely, the specification of the market-model regression is as follows

$$\begin{aligned} DL_{i,t} &= \alpha_i + \beta_{M,i}^1 DL_{M,i,t} + \beta_{M,i}^2 DL_{M,i,t-1} + \beta_{M,i}^3 DL_{M,i,t+1} \\ &\quad + \gamma_i^1 R_{M,t} + \gamma_i^2 R_{M,t-1} + \gamma_i^3 R_{M,t+1} + \delta_i DV_{i,t} + \varepsilon_{i,t}, \end{aligned} \tag{4}$$

Table 1

Descriptive statistics

This table reports the descriptive statistics of our sample stocks, which include 1,024 U.S. ordinary stocks listed on the NYSE from January 2003 to December 2003. “Limit Order Book Dispersion” is defined as

$$LDispersion_i = \frac{1}{2}\left(\frac{\sum_{j=1}^{n} w_j^{Buy}\, Dst_j^{Buy}}{\sum_{j=1}^{n} w_j^{Buy}} + \frac{\sum_{j=1}^{n} w_j^{Sell}\, Dst_j^{Sell}}{\sum_{j=1}^{n} w_j^{Sell}}\right),$$

where $Dst_j^{Buy} = (Bid_{j-1} - Bid_j)$ and $(Dst_j^{Sell} = (Ask_j - Ask_{j-1}))$ is the price interval on the bid (ask) side of the limit order book and w_j^{Buy} (w_j^{Sell}) is the bid (ask) size. “Best 5 Quotes” (“Best 10 Quotes”) means that n equals 5 (10). “Limit Order Book Cost-to-Trade 1%” (2%) measures the round-trip trading cost to use market orders to simultaneously buy and sell 1% (2%) of the stock’s average daily trading volume against the limit order book. “Bid-Ask Spread” stands for the price difference between the best ask and best bid quote. “Quoted spread (%)” is the bid-ask spread scaled by the mid-quote, and “Quoted Spread (cents)” measures the bid-ask spread in cents. We report the cross-sectional statistics of individual stock’s time series average of liquidity level measures for both the overall sample and the portfolios sorted by firm size at the end of 2002.

		Limit order book dispersion		Limit order book cost-to-trade		Bid-ask spread (from TAQ)	
		Best 5 quotes (cents)	Best 10 quotes (cents)	1% (%)	2% (%)	Quoted spread (%)	Quoted spread (cents)
All sample stocks							
	Mean	6.15	11.84	1.94%	3.50%	0.18%	3.18
	Sigma	5.69	10.00	1.14%	2.20%	0.18%	1.36
	Q1	2.31	4.07	1.15%	2.00%	0.08%	2.30
	Median	4.02	8.59	1.72%	3.14%	0.17%	2.86
	Q3	8.12	17.75	2.45%	4.48%	0.19%	3.69
Quintile portfolios sorted by firm size							
Quintile 1	Mean	2.03	3.33	1.32%	1.74%	0.07%	2.56
(Large stocks)	Median	1.80	2.73	1.22%	1.67%	0.06%	2.40
Quintile 2	Mean	3.62	7.82	1.72%	3.30%	0.10%	2.67
	Median	2.90	6.03	1.55%	3.15%	0.09%	2.53
Quintile 3	Mean	5.46	12.79	1.92%	3.80%	0.13%	2.84
	Median	4.63	11.18	1.67%	3.42%	0.11%	2.67
Quintile 4	Mean	8.48	17.31	2.21%	4.40%	0.18%	3.48
	Median	7.21	16.00	2.03%	3.96%	0.15%	3.18
Quintile 5	Mean	11.48	18.77	2.80%	4.79%	0.40%	4.18
(Small stocks)	Median	10.03	17.63	2.50%	4.31%	0.32%	3.71

where $DL_{i,t}$ is the percent change in the liquidity measure for stock i on day t, $DL_{M,i,t}$, $DL_{M,i,t-1}$, and $DL_{M,i,t+1}$ are the percent changes in the market average liquidity measure (excluding stock i) on day t, t–1, and t+1, respectively; $R_{M,t}$, $R_{M,t-1}$, and $R_{M,t+1}$ are the market returns on day t, t–1, and t+1, respectively; and $DV_{i,t}$ is the percent change in the squared return, which is the volatility measure of stock i on day t.

We add the leads and lags of the changes in the market average liquidity measures to capture the effect of nonconcurrent adjustments in the liquidity variation at stock and market level. Consistent with Chordia, Roll and Subrahmanyam (2000), when calculating the market average liquidity for stock i, we take the equally weighted average liquidity of all stocks other than stock i to exclude the effect of stock i's own liquidity variation on the market average and remove the mechanical constraint that the cross-sectional average of the beta has to be one. The control variables include market returns and the change in stock volatility, since studies have shown that both of these factors have significant influences on the stock liquidity variation (e.g., Stoll, 1978; Grossman and Miller, 1988; Hameed, Kang and Viswanathan, 2010).

We first conduct the time series analysis using Equation (4) for each stock, and then report the cross-sectional mean and median of the estimated beta coefficients. Columns 1 to 4 in Table 2 provide strong empirical evidence of the limit order book commonality. For example, for the limit order book dispersion measure based on the best five quotes, the contemporaneous beta estimate β_M^1 displays a cross-sectional average of 1.04, which is highly significant even after adjusting the cross-equation correlation.[4] All of our sample stocks have positive contemporaneous beta estimates and 93.1% of them are positively significant at the 95% confidence level. The lead and lag beta estimates (β_M^2 and β_M^3) are usually small and insignificant compared with the contemporaneous beta. Therefore, the sum of the beta estimates has a similar value to the contemporaneous betas, and hereafter we only report the estimated contemporaneous beta coefficients and the sum of all three beta estimates.[5] Similarly, for the limit order book cost-to-trade measure based on 1% of daily trading

[4] The t-statistics associated with the mean coefficients in Table 2 have been adjusted for cross-equation correlations. We extend the correction in standard errors proposed in Chordia, Roll and Subrahmanyam (2000) by allowing the variance and pairwise covariances between coefficient estimates to vary across securities. The variance of each estimated coefficient $\beta_{M,i}$ is obtained from stock i's market model liquidity commonality regression in Equation (4). The empirical correlation between the regression residuals for stocks i and j is used to estimate the pairwise correlation between the coefficients $\beta_{M,i}$ and $\beta_{M,j}$. Hence, the standard error of the mean estimated coefficient is provided by:

$$StdDev(\bar{\beta}_M) = StdDev\left(\frac{1}{N}\sum_{i=1}^{N}\beta_{M,i}\right) = \frac{1}{N}\sqrt{\sum_{i=1}^{N}Var(\beta_{M,i}) + \sum_{i=1}^{N}\sum_{j=1,j\neq i}^{N}\rho_{i,j}\sqrt{Var(\beta_{M,i})Var(\beta_{M,j})}}$$

[5] For the sum of the beta coefficients, since the market model regression in Equation (4) does not provide its variance estimate, we cannot use the t-statistic adjustment procedure, mentioned in the previous footnote, directly. Therefore, to ascertain whether the sum of the beta coefficient estimates also is significant, we follow the original method in Chordia, Roll and Subrahmanyam (2000). We sort the sample stocks alphabetically by their name and find the average correlations between the residuals of Equation (4) for stock $j+1$ and stock j are smaller than 0.028. The t-statistics, after the cross-equation dependence adjustment using this method, are above 7.2 for all of the limit order book liquidity measures.

Table 2

Market-level commonality in liquidity

Daily percent changes in individual stock *i*'s limit order book liquidity measures are regressed on daily percent changes in the market aggregate limit order book liquidity measures, which is an equally weighted average of limit order book liquidity measures of all sample stocks excluding stock *i* itself, on day *t*, *t*−1 and *t*+1. The concurrent, lag and lead market daily returns and the percent change in stock *i*'s squared daily return as the volatility measure are included as the control variables. The limit order book liquidity measures include the limit order book dispersion and cost-to-trade measure, defined in the same way as in Table 1. We also apply the same regression specification on the quoted spread measures. Cross-sectional statistics of time series regression coefficient estimates are reported with *t*-statistics adjusted for cross-equation correlation in parentheses. The coefficient estimates for the control variables are not reported for simplicity.

	Limit order book dispersion		Limit order book cost-to-trade		Bid-ask spread	
	Best 5 quotes	Best 10 quotes	1%	2%	Quoted spread (%)	Quoted spread (cents)
Concurrent						
Mean	1.044***	1.106***	1.051***	0.981***	0.970***	0.998***
(*t*-statistics)	(*52.99*)	(*49.16*)	(*40.42*)	(*26.37*)	(*34.15*)	(*70.75*)
Median	0.958	1.074	0.991	0.949	0.947	0.971
% positive	100.00%	100.00%	98.24%	91.89%	97.07%	97.85%
% positive significant	93.07%	94.34%	81.93%	57.13%	77.44%	80.86%
Lag						
Mean	0.035*	0.022	0.023	0.016	0.012	0.026**
(*t*-statistics)	(*1.85*)	(*1.02*)	(*0.96*)	(*0.47*)	(*0.47*)	(*1.97*)
Median	0.034	0.019	0.012	0.025	0.021	0.035
% positive	59.47%	54.30%	51.37%	51.95%	52.44%	55.18%
% positive significant	5.86%	5.96%	7.42%	6.74%	5.96%	6.05%
Lead						
Mean	−0.010	0.016	−0.005	−0.003	0.053**	0.012
(*t*-statistics)	(*−0.53*)	(*0.74*)	(*−0.20*)	(*−0.09*)	(*2.10*)	(*0.92*)
Median	0.001	0.016	−0.024	−0.002	0.037	0.004
% positive	50.39%	53.23%	46.97%	49.90%	54.88%	50.29%
% positive significant	5.18%	5.86%	6.05%	5.76%	9.47%	7.42%
Sum						
Mean	1.070	1.144	1.068	0.994	1.034	1.035
Median	0.993	1.109	0.979	0.972	1.006	1.010
Adjusted R^2	17.05%	11.01%	6.09%	2.97%	6.61%	7.26%

*,**,*** indicate statistical significance at the 0.10, 0.05 and 0.01 level, respectively.

volume, the cross-sectional average of the contemporaneous beta estimates is 1.05. A total of 98.2% of our sample stocks have positive contemporaneous beta estimates and 81.9% of them are positively significant at the 95% confidence level. We also notice that when we extend our limit order book cost-to-trade measure from being based on 1% of daily volume to 2%, we find that the significance of our liquidity comovement estimates decrease. For example, the average contemporaneous beta decreases from 1.05 to 0.98. The percentage of sample stocks with significant positive contemporaneous beta estimates decreases from 81.9 to 57.1%. This finding suggests that there tends to be less liquidity comovement once we go deeper into the limit order book. It motivates our following test of difference in commonality between the limit order book inside and outside liquidity measure.

4. Inside liquidity versus outside liquidity

Many of the previous liquidity commonality studies (e.g., Chordia, Roll and Subrahmanyam, 2000; Coughenour and Saad, 2004) use liquidity measures that capture the cost of executing a small-size market order (e.g., the bid-ask spread). However, when there is a large demand for liquidity in the market, the liquidity-consuming market orders will walk further up and down into the limit order book to seek the immediacy of their order execution. Therefore, for the liquidity that lies beyond the best quotes posted on the exchange, we would like to know how it comoves across the market. To address this question, we first divide the limit order book into three parts, and measure the limit order book dispersion based on the first and second best quotes (labeled as "inside liquidity"), the dispersion from the third to the fifth best quotes (labeled as "medium liquidity"), and the dispersion from the sixth to the tenth best quotes (labeled as "outside liquidity"). In Table 3, Panel A shows that the average dispersion measure for these three parts of the limit order book are 3.48, 7.55, and 16.95 cents, respectively. This is consistent with our previous observation that, when limit order quotes move away from midquote, they become more dispersed. One possible explanation for this phenomenon is that, as suggested by Chiao and Wang (2009), the tendency for limit order traders to submit orders at round and even price points increases when their limit orders become less marketable, that is, further away from the midquote. Panel B provides the correlations among these three liquidity measures. The low correlation between the inside and outside liquidity measures (0.27) suggests that these two measures represent different dimensions of liquidity provided by the limit order book.

On the NYSE, the specialists and other active floor traders are more likely to be providers of inside liquidity, since they need to maintain the continuity of stock price. Recent studies, such as Comerton-Forde, Hendershott, Jones, Moulton and Seasholes (2010), show that the specialist's market-making behavior is influenced by market state variables such as market returns and volatility. Therefore, we should expect high commonality of inside liquidity in the limit order book. On the other hand, outside liquidity could have a different nature compared with inside liquidity. For example, our data suggest that the second best limit order quote is approximately 0.3% away from the midquote, while the tenth best quote is around 5.9% away from the midquote. In other words, the tenth best limit order quote presents a much deeper price discount than the second best limit order quote. In our sample period, the standard deviation of

Table 3

Descriptive statistics for the inside and outside limit order book liquidity measures

For each individual stock, we divide its limit order book into three parts, and measure the limit order book dispersion based on the first and second best bid and ask quotes (“inside liquidity”), the dispersion from the third to the fifth best quotes (“medium liquidity”), and the dispersion from the sixth to the tenth best quotes (“outside liquidity”). The calculation method for the dispersion measure is same as introduced above. Panel A shows the cross-sectional statistics of each individual stock’s limit order book inside, medium and outside liquidity measures. The cross-sectional average of the time series correlations among the three measures at the individual stock level is presented in Panel B.

Panel A: Sample statistics

	Limit order book dispersion (cents)		
	Inside liquidity (based on the 1st to 2nd best quotes)	Medium liquidity (based on the 3rd to 5th best quotes)	Outside liquidity (based on the 6th to 10th best quotes)
Mean	3.48	7.55	16.95
Sigma	2.73	6.98	14.34
Q1	1.71	2.70	5.35
Median	2.58	4.83	12.13
Q3	4.22	10.24	25.97

Panel B: Correlations

		Limit order book dispersion		
		Inside liquidity	Medium liquidity	Outside liquidity
Limit order book dispersion	Inside liquidity	1.000	0.402	0.272
	Medium liquidity		1.000	0.548
	Outside liquidity			1.000

daily market returns is 1.0%. Therefore, the second best limit order quote easily can be filled once there is a market-wide stock price fluctuation, while the investor who places the tenth best quote knows that she probably needs some idiosyncratic shock to occur for her deeply discounted limit order to be executed. In other words, outside liquidity, which is provided by limit order quotes far away from the midquote, is more likely to be subject to the impact of firm-specific news.[6] Hence, our hypothesis is that the limit order book outside liquidity measure should exhibit lower commonality than the inside liquidity measure.

To test this hypothesis, we apply the same stock-by-stock time series regression specification as in the section above for each of the limit order book inside, medium, and outside liquidity measures. To be precise, we estimate the following regressions:

[6] Chung, Van Ness and Van Ness (2004) show that the adverse selection component of the bid-ask spread estimated from specialist quotes is significantly smaller than those from limit-order quotes on NYSE, suggesting that specialists differ from limit order traders in their ability to incorporate adverse selection cost.

$$DL_{\Psi,i,t} = \alpha_i + \beta^1_{M,i} DL_{\Psi,M,i,t} + \beta^2_{M,i} DL_{\Psi,M,i,t-1} + \beta^3_{M,i} DL_{\Psi,M,i,t+1} + \gamma_i^1 R_{M,t} + \gamma_i^2 R_{M,t-1} + \gamma_i^3 R_{M,t+1} + \delta_i DV_{i,t} + \varepsilon_{i,t} \quad (5)$$

$$\begin{aligned} DL_{\Psi,i,t} = {} & \alpha_i + \beta^1_{M,i} DL_{Inside,M,i,t} + \beta^2_{M,i} DL_{Inside,M,i,t-1} + \beta^3_{M,i} DL_{Inside,M,i,t+1} \\ & + \omega^1_{M,i} DL_{Medium,M,i,t} + \omega^2_{M,i} DL_{Medium,M,i,t-1} + \omega^3_{M,i} DL_{Medium,M,i,t+1} \\ & + \varphi^1_{M,i} DL_{Outside,M,i,t} + \varphi^2_{M,i} DL_{Outside,M,i,t-1} + \varphi^3_{M,i} DL_{Outside,M,i,t+1} \\ & + \gamma_i^1 R_{M,t} + \gamma_i^2 R_{M,t-1} + \gamma_i^3 R_{M,t+1} + \delta_i DV_{i,t} + \varepsilon_{i,t} \\ & (\Psi \in \{\textit{inside liquidity}, \textit{medium liquidity}, \textit{outside liquidity}\}), \end{aligned} \quad (6)$$

where $DL_{\Psi,i,t}$ refers to the percent change in the limit order book inside, medium, and outside liquidity measures, depending on Ψ's value, for stock i on day t; $DL_{Inside,M,i,t}$, $DL_{Medium,M,i,t}$, and $DL_{Outside,M,i,t}$ are the percent changes in the market average limit order book inside, medium, and outside liquidity measures (excluding stock i) on day t, respectively. All the control variables are defined in the same way as in previous section.

Equation (5) represents a "univariate" liquidity commonality regression for each of the inside, medium, and outside liquidity measures. The results in Table 4 Panel A show that the limit order book inside liquidity dispersion measure exhibits higher commonality (an adjusted R^2 of 31.64%) than outside liquidity dispersion measure (an adjusted R^2 of 6.80%). In Panel B, the "multivariate" commonality regression suggests that the stock-level inside (outside) liquidity mainly comoves with the market-level inside (outside) liquidity. Furthermore, the results in Panel B confirm that the degree of liquidity commonality decreases when moving from inside to outside liquidity.

So far, we have provided empirical evidence about the commonality of inside and outside liquidity. To better understand why outside liquidity exhibits less commonality than inside liquidity, we now explore how these two measures are influenced by an important liquidity determinant, volatility. Studies suggest that volatility is closely related to liquidity provision in the stock market. Earlier papers, such as Stoll (1978), Ho and Stoll (1980), and Grossman and Miller (1988), show that high volatility will increase the market maker's inventory risk and therefore reduce liquidity. In addition to the general relation between market liquidity and volatility described earlier, volatility also carries particular importance for limit order traders. Placing a limit buy (sell) order can be interpreted as writing an out-of-the-money put (call) option (see Copeland and Galai, 1983). Foucault, Moinas and Theissen (2007) show that informed market makers who receive signals about high volatility will post less aggressive limit orders, leading to a thin book. Uninformed market makers, who observe the large dispersion in the limit order book, interpret this as the expectation of high volatilities by informed market makers and hence also are less willing to post limit orders. As a result, high volatility leads to less liquidity provided by the limit order book.

When examining the inside versus outside liquidity in the limit order book, we distinguish between the market and idiosyncratic volatility. First, as discussed earlier, market volatility should mainly affect inside liquidity in the limit order book. Second, the impact of market volatility on liquidity should be asymmetric; that is, downside market volatility could have a higher influence than upside market movement. In the collateral-constraint model of Brunnermeier and Pedersen (2009), market makers face funding constraints and need to finance their market making behavior by pledging the securities they hold as collateral. At any particular moments, the market makers, especially the specialists, can take either long or short positions

Table 4

Commonality in the inside and outside liquidity provided by the limit order book

In Panel A, the percent change in the limit order book inside liquidity measures on day t is regressed on the percent change in the market average limit order book inside liquidity measures (excluding stock i) on day t, t–1 and t+1. Similar regressions are performed for the limit order book medium and outside liquidity measures. In Panel B, the percent change in the limit order book inside liquidity measures on day t is regressed on the percent change in the market average limit order book inside, medium and outside liquidity measures (excluding stock i) on day t, t–1 and t+1. Similar regressions are performed for the limit order book medium and outside liquidity measures. All the control variables are defined in the same way as in Table 2. Cross-sectional statistics of time series regression coefficient estimates are reported with t-statistics adjusted for cross-equation correlation in parentheses. The coefficient estimates for the control variables are not reported for simplicity.

Panel A: "Univariate" commonality regressions

	Limit order book dispersion		
	Inside liquidity	Medium liquidity	Outside liquidity
Concurrent			
Mean	1.010***	0.975***	1.130***
(t-statistics)	(*32.25*)	(*12.81*)	(*10.22*)
Median	1.036	0.904	1.173
% positive	94.84%	90.86%	91.34%
% positive significant	90.18%	73.05%	78.79%
Lag			
Mean	−0.001	0.004	0.016
(t-statistics)	(*−0.05*)	(*0.07*)	(*0.16*)
Median	−0.008	–0.005	0.001
% positive	46.50%	48.74%	50.29%
% positive significant	6.32%	4.57%	6.03%
Lead			
Mean	0.024	–0.077	−0.069
(t-statistics)	(*0.96*)	(*−1.21*)	(*−0.68*)
Median	0.020	–0.073	−0.056
% positive	58.17%	36.09%	42.80%
% positive significant	12.74%	2.72%	2.43%
Sum			
Mean	1.032	0.902	1.077
Median	1.048	0.827	1.118
Adjusted R^2	31.64%	9.67%	6.80%

(Continued)

Table 4 *(continued)*

Commonality in the inside and outside liquidity provided by the limit order book

Panel B: "Multivariate" commonality regressions

			Limit order book dispersion		
			Inside liquidity	Medium liquidity	Outside liquidity
Market average limit order book dispersion	Inside liquidity	Concurrent			
		Mean	1.034***	0.056	0.119**
		(t-statistics)	(*57.13*)	(*1.23*)	(*2.15*)
		Median	1.077	0.044	0.098
		% positive	94.14%	59.47%	64.06%
		% positive significant	89.75%	16.89%	24.51%
		Sum			
		Mean	1.069	0.092	0.140
		Median	1.090	0.049	0.115
	Medium liquidity	Concurrent			
		Mean	0.114***	0.515***	0.077
		(t-statistics)	(*2.48*)	(*4.25*)	(*0.53*)
		Median	−0.227	0.814	−0.020
		% positive	38.18%	83.20%	49.22%
		% positive significant	14.65%	60.55%	15.53%
		Sum			
		Mean	0.131	0.591	0.063
		Median	−0.284	0.806	−0.065
	Outside liquidity	Concurrent			
		Mean	0.159***	−0.149	0.521***
		(t-statistics)	(*2.66*)	(*−0.90*)	(*2.57*)
		Median	0.052	−0.294	0.751
		% positive	53.91%	33.11%	80.86%
		% positive significant	11.33%	3.91%	29.59%
		Sum			
		Mean	0.202	−0.184	0.473
		Median	0.047	−0.465	0.659
		Adjusted R^2	33.53%	10.98%	8.23%

,* indicate statistical significance at the 0.05 and 0.01 level, respectively.

depending on the order flow and their inventory rebalancing needs. But on average, market makers are typically in a long position.[7] Hence, a market decline will increase

[7] Hendershott and Seasholes (2007) show that the aggregate inventory levels of specialists have a maximum of $1 billion (long) and a minimum of -$200 million (short). Comerton-Forde, Hendershott, Jones, Moulton and Seasholes (2010) show that the specialist firm aggregate inventory is negative only 163 of the 2,770 days in their sample, so specialists in aggregate are net long 94% of the time. At the specialist firm level, an average given specialist firm is net long 83% of the time.

the probability that they will hit their margin constraints and be forced to liquidate. Therefore, a negative market shock will accelerate the switch from high liquidity to low liquidity equilibrium, and exert more influence on the market liquidity than a positive shock. Kyle and Xiong (2001) and Xiong (2001) provide similar results through their limits-to-arbitrage models in which, when facing downside market movements, the arbitrageurs with decreasing absolute risk aversion preferences have less appetite for risky assets, and are therefore able to provide a smaller amount of liquidity to the market. We should notice that, in all of these models, the market makers are holding a portfolio of stocks, and hence pay attention to downside market movements rather than downside idiosyncratic volatilities. Also, the market return is left-skewed, in other words, the left-tail risk is more important than the right-tail risk for market returns.

As a comparison, the idiosyncratic volatility matters more for outside liquidity provided by the limit order book, and there is no particular reason to argue that its impact on liquidity only comes from the downside. As we discussed earlier, the limit order traders who place deeply discounted limit orders are betting on large stock price movements, which are more likely to be based on stock-level events, such as earning surprises or outside acquisition bids. Actually, some studies (e.g., Duffee, 1995) suggest that the idiosyncratic return is more likely to exhibit positive skewness. Taken together, we expect that market volatility and idiosyncratic volatility will influence the inside and outside liquidity provided by the limit order book differently.

To test the effect of market and idiosyncratic volatilities on inside and outside liquidity, we start by separating them into upside and downside volatility measures. For example, for market volatility, we measure the upside (downside) market volatility by the variable $abs(lagmktret)_{i,pos}$ ($abs(lagmktret)_{i,neg}$), which is defined as the absolute value of the past five-day market return, if the past five-day market return is positive (negative), and zero otherwise.[8] The upside (downside) idiosyncratic volatility measure $abs(lagidiosynret)_{i,pos}$ ($abs(lagidiosynret)_{i,neg}$) is similarly calculated based on the past five-day idiosyncratic return, which is the residual from one-factor market model return regression. Next, we perform the following stock-level time series regressions:

$$DL_{\psi,i,t} = \alpha_i + \theta_{i,pos}\, abs(lagmktret)_{i,pos} + \theta_{i,neg}\, abs(lagmktret)_{i,neg} + \sum_{h=1}^{5} \delta_{i,h} DL_{\psi,i,t-h} + \varepsilon_{i,t} \quad (7)$$

[8] Our downside volatility measure is conceptually close to semivariance. The difference between the exact definition of semivariance and our downside volatility measure is that semivariance is conditional on return less than its average, while our downside volatility measure is conditional on return less than zero, since the theoretical models of Brunnermeier and Pedersen (2009) and Kyle and Xiong (2001) suggest that it is downside price movement that will add more funding constraints to market makers and reduce their risk-taking capability.

$$DL_{\psi,i,t} = \alpha_i + \theta_{i,pos}\, abs(lagidiosynret)_{i,pos} + \theta_{i,neg}\, abs(lagidiosynret)_{i,neg} + \sum_{h=1}^{5} \delta_{i,h} DL_{\psi,i,t-h} + \varepsilon_{i,t} \quad (8)$$

$$(\Psi \in \{inside\ liquidity, medium\ liquidity, outside\ liquidity\}),$$

where $DL_{\psi,i,t}$ stands for the percent changes in the limit order book inside, medium, and outside liquidity measures, depending on Ψ's value, and $DL_{\psi,i,t-h}$ is the lag value of $DL_{\psi,i,t}$ up to five trading days.

The results in Table 5 show that the inside liquidity provided by the limit order book responds asymmetrically to market volatility—it decreases when downside market volatility increases, but does not necessarily do so in response to an increase in upside market volatility. The idiosyncratic volatility has little impact on inside liquidity. On the other hand, the outside liquidity provided by the limit order book is reduced by both upside and downside idiosyncratic volatility, but is not influenced by market volatility. Furthermore, the upside idiosyncratic volatility has a stronger impact on the limit order book outside liquidity measures, which is probably because of large extreme returns that are more likely to happen on the upside rather than the downside for stock-level price movements. The contrast between the relation of inside and outside liquidity with market and idiosyncratic volatility suggests that inside liquidity is determined by market-wide systematic factors, while outside liquidity is more likely to be affected by stock-level idiosyncratic factors.[9] Therefore, it is natural for the limit order book inside liquidity measure to show more comovement than the outside liquidity measure.

In brief, in this section, we examine the commonality of an unexplored dimension of liquidity, that is, outside liquidity provided by limit orders far away from the midquote. We find outside liquidity exhibits substantially less commonality than inside liquidity. Our empirical results further suggest that market volatility determines inside liquidity, while the influence of idiosyncratic volatility is mainly exerted on outside liquidity.

5. Extension of empirical analysis

5.1. Industry-specific limit order book commonality

Chordia, Roll and Subrahmanyam (2000) suggest that an individual stock's liquidity could comove within a specific industry, on top of the market-wide liquidity

[9] We conduct time series regression of the changes in inside, medium and outside limit order book liquidity on stock-level return skewness and kurtosis measures estimated from past 30 days for each stock in our sample. The unreported results show that an increase in the stock return skewness and kurtosis measures can reduce the outside liquidity on the limit order book, but has little influence on the limit order book inside liquidity measures. It suggests that extreme stock-level returns, particularly upside stock returns, can lower the outside liquidity on the limit order book, but not necessarily for the inside liquidity.

Table 5

Volatility and limit order book liquidity

In this table, the percent change in stock i's inside, medium or outside limit order book liquidity measures is regressed on upside and downside market and idiosyncratic volatility measures:

$$DL_{\psi,i,t} = \alpha_i + \theta_{i,pos}\, abs(lagmktret)_{i,pos} + \theta_{i,neg}\, abs(lagmktret)_{i,neg} + \sum_{h=1}^{5} \delta_{i,h} DL_{\psi,i,t-h} + \varepsilon_{i,t}$$

$$DL_{\psi,i,t} = \alpha_i + \theta_{i,pos}\, abs(lagidiosynret)_{i,pos} + \theta_{i,neg}\, abs(lagidiosynret)_{i,neg} + \sum_{h=1}^{5} \delta_{i,h} DL_{\psi,i,t-h} + \varepsilon_{i,t}$$

$$(\Psi \in \{inside\ liquidity, medium\ liquidity, outside\ liquidity\}),$$

where $DL_{\Psi,i,t}$ stands for the percent change in the limit order book inside, medium, and outside liquidity measures; $abs(lagmktret)_{i,pos}$ ($abs(lagmktret)_{i,neg}$) is a measure of upside (downside) market volatility and is defined as the absolute value of past five-day market return if the past five-day market return is positive (negative) and zero otherwise; $abs(lagidiosynret)_{i,pos}$ ($abs(lagidiosynret)_{i,neg}$) is the upside (downside) idiosyncratic volatility measure and is calculated based on the past five-day idiosyncratic return in a similar way; and $DL_{\Psi,i,t-h}$ is the lag value of $DL_{\Psi,i,t}$ up to five trading days. Cross-sectional mean and median of the time series regression coefficient estimates are reported with t-statistics adjusted for cross-equation correlation in parentheses. "Adjusted R^2" is the cross-sectional mean of the adjusted R^2 in regressions for all the individual stock.

	Limit order book dispersion		
	Inside liquidity	Medium liquidity	Outside liquidity
Market volatility test			
$abs(lagmktret)_{i,pos}$			
Mean	−0.844	0.501	−0.317
(t-statistics)	(*−0.85*)	(*0.86*)	(*−0.60*)
Median	−1.056	0.493	−0.347
$abs(lagmktret)_{i,neg}$			
Mean	3.322***	1.621**	1.243
(t-statistics)	(*2.56*)	(*2.14*)	(*1.55*)
Median	3.078	1.339	1.137
Adjusted R^2	14.058%	17.863%	15.143%
Idiosyncratic volatility test			
$abs(lagidiosynret)_{i,pos}$			
Mean	−0.038	0.070	0.371***
(t-statistics)	(*−0.53*)	(*0.96*)	(*6.58*)
Median	−0.112	−0.010	0.188
$abs(lagidiosynret)_{i,neg}$			
Mean	0.018	0.105*	0.163***
(t-statistics)	(*0.26*)	(*1.81*)	(*2.65*)
Median	0.103	0.067	0.071
Adjusted R^2	12.86%	17.63%	17.12%

*,**,*** indicate statistical significance at the 0.10, 0.05 and 0.01 level, respectively.

commonality mentioned above. To further examine whether there is any industry-specific limit order book commonality, we consider a "two-factor" model, which includes the market aggregate liquidity and industry-specific liquidity provided by the limit order books. More specifically, we use the following regression

$$
\begin{aligned}
DL_{i,t} = {} & \alpha_i + \beta^1_{M,i} DL_{M,i,t} + \beta^2_{M,i} DL_{M,i,t-1} + \beta^3_{M,i} DL_{M,i,t+1} \\
& + \beta^1_{IND,i} DL_{IND,i,t} + \beta^2_{IND,i} DL_{IND,i,t-1} + \beta^3_{IND,i} DL_{IND,i,t+1} \\
& + \gamma_i^1 R_{M,t} + \gamma_i^2 R_{M,t-1} + \gamma_i^3 R_{M,t+1} + \delta_i DV_{i,t} + \varepsilon_{i,t}.
\end{aligned}
\tag{9}
$$

Industry-specific liquidity for stock i at day t, $L_{IND,i,t}$, is the equally weighted average of the liquidity measures of all stocks within that industry, excluding stock i itself. To control for the correlation between the market aggregate liquidity and the industry-specific liquidity, we exclude all stocks within the industry to which stock i belongs, when calculating the market-wide liquidity for stock i, $DL_{M,i,t}$.

The results in Table 6 show that the coefficient estimates of both the market aggregate and industry-specific liquidity, for all the limit order book liquidity measures, are statistically significant. The contemporaneous beta estimates of the industry-specific liquidity measures range from approximately 0.19 to 0.22, while the contemporaneous beta estimates of the market aggregate liquidity measures have higher values (from 0.79 to 0.91). Our results imply that industry-specific limit order book commonality exists, but the liquidity provided by an individual stock's limit order book is influenced more by the market-wide component than by the industry-specific component. Our finding on the industry-specific limit order book commonality suggests industry-specific risk matters not only for the specialists, but also for other types of market makers, for example, limit order traders. Stocks in the same industry are subject to the influence of industry-specific news, such as the change of industry regulation. Such news events can produce industry-wide information asymmetry. At the same time, they also will lead to comovement of returns and volatility for all the stocks within the industry. Therefore, the market makers (including limit order traders), who are either risk averse or worry about adverse selection, will incorporate the industry-specific risk into their liquidity provision strategy.

5.2. *Limit order book commonality and overall stock market liquidity commonality*

An intriguing question since the discovery of commonality in liquidity is why liquidity comoves. Our study of the limit order book commonality has the potential to shed light on this important question. Given that limit order traders are one of the vital sources of liquidity in the market, if their willingness or aggressiveness to trade via limit orders comoves with others, there will naturally be commonality in the overall stock market liquidity. In this section, we use proportional bid-ask spread as

Table 6

Market-level and industry-level commonality in liquidity

In this table, daily percent changes in individual stock i's liquidity measures are regressed on daily percent changes in the market aggregate liquidity measures, daily percent changes in the industry-specific liquidity measures and the control variables:

$$DL_{i,t} = \alpha_i + \beta^1_{M,i} DL_{M,i,t} + \beta^2_{M,i} DL_{M,i,t-1} + \beta^3_{M,i} DL_{M,i,t+1} + \beta^1_{IND,i} DL_{IND,i,t} + \beta^2_{IND,i} DL_{IND,i,t-1} + \beta^3_{IND,i} DL_{IND,i,t+1} + \gamma_i^1 R_{M,t} + \gamma_i^2 R_{M,t-1} + \gamma_i^3 R_{M,t+1} + \delta_i DV_{i,t} + \varepsilon_{i,t},$$

where $DL_{IND,i,t}$ is the percent change in industry-specific liquidity measure for stock i on day t, which is the equally weighted average of liquidity measure of all stocks within that industry excluding stock i; $DL_{M,i,t}$ is the percent change in market liquidity for stock i on day t which is the equally weighted average of liquidity across all stocks excluding those within the industry to which stock i belongs. We group stocks into industries using the Fama-French 17 industries standard. All the other variables are defined in a same way as in the previous tables. Cross-sectional averages and other statistics of time series coefficient estimates are reported with t-statistics adjusted for cross-equation correlation in parentheses.

		Dependent variable = Individual stock liquidity measures					
		Limit order book dispersion		Limit order book cost-to-trade		Bid-ask spread	
		Best 5 quotes	Best 10 quotes	1%	2%	Quoted spread (%)	Quoted spread (cents)
	Concurrent						
	Mean	0.850***	0.907***	0.833***	0.785***	0.715***	0.653***
	(t-statistics)	(*16.97*)	(*16.31*)	(*17.91*)	(*13.72*)	(*18.48*)	(*26.96*)
Market	Median	0.770	0.843	0.757	0.792	0.691	0.677
average	% positive	92.19%	90.43%	88.18%	82.81%	87.99%	80.37%
liquidity	% positive significant	59.96%	48.63%	39.65%	29.49%	42.48%	35.74%
	Sum						
	Mean	0.850	0.977	0.852	0.766	0.739	0.620
	Median	0.776	0.907	0.744	0.792	0.734	0.661
	Concurrent						
	Mean	0.189***	0.197***	0.216***	0.192***	0.244***	0.334***
	(t-statistics)	(*4.34*)	(*4.01*)	(*5.54*)	(*4.29*)	(*8.11*)	(*16.13*)
Industry	Median	0.108	0.151	0.171	0.141	0.211	0.252
average	% positive	63.87%	63.28%	63.96%	60.94%	71.88%	69.92%
liquidity	% positive significant	13.18%	12.60%	12.40%	8.01%	14.45%	17.58%
	Sum						
	Mean	0.212	0.165	0.209	0.215	0.281	0.396
	Median	0.118	0.142	0.194	0.138	0.232	0.298
	Adjusted R^2	17.37%	11.26%	6.51%	3.28%	6.86%	7.85%

*** indicates statistical significance at the 0.01 level.

the measure of the overall stock market liquidity.[10] The previously introduced limit order book liquidity measures can be interpreted as proxies for the willingness of investors to trade via limit orders. For example, a large dispersion in the limit order book or a high cost-to-trade suggests that limit order traders are more concerned about the information asymmetry and therefore require a large price concession as the compensation for providing liquidity to the market. Hence, for a particular stock, if its limit order traders' order-placing strategies are more correlated with the aggregate limit order traders' behavior, it is likely that its bid-ask spread will comove more with the market average spread.

As the first step, we take a look at the correlation between the commonality measures (the beta and R^2 estimates) estimated from Equation (4) above, for both the bid-ask spread and the limit order book liquidity measures. As shown in Table 7, the concurrent beta coefficients and the adjusted R^2 estimates from "market-model" liquidity commonality regression by using the bid-ask spread and the limit order book liquidity measures are significantly positively correlated with each other. These results imply that, for the stock whose limit order book has high commonality with the market aggregate limit order book measures, its bid-ask spread also comoves more with the market average spread.

Next, we examine more specifically how much the limit order book comovements contribute to the bid-ask spread comovements. To address this empirical question, we regress the change in the stock spread on the changes in the market average spread and in the market aggregate limit order book liquidity measure. But we should notice that these two market-level aggregate liquidity variables are correlated with each other, since the bid-ask spread is jointly determined by limit order traders, specialists, and other market makers. Therefore, we need to disentangle these two market-level liquidity variables. In the first approach, we orthogonalize market-level spread change on the change in the market aggregate limit order book liquidity measure. After this orthogonalization, we regress the change in stock-level spread on the lead, lag, and concurrent values of the change in liquidity provided by the market aggregate limit order book (DL_{LOBM}) and the orthogonalized market-level spread change (DL_{OM}), as well as other control variables defined in the same way as in Equation (4).

$$\begin{aligned} DSpread_{i,t} = \alpha_i &+ \beta^1_{LOBM,i} DL_{LOBM,i,t} + \beta^2_{LOBM,i} DL_{LOBM,i,t-1} + \beta^3_{LOBM,i} DL_{LOBM,i,t+1} \\ &+ \beta^1_{OM,i} DL_{OM,i,t} + \beta^2_{OM,i} DL_{OM,i,t-1} + \beta^3_{OM,i} DL_{OM,i,t+1} \\ &+ \gamma_i^1 R_{M,t} + \gamma_i^2 R_{M,t-1} + \gamma_i^3 R_{M,t+1} + \delta_i DV_{i,t} + \varepsilon_{i,t}. \end{aligned} \tag{10}$$

The results in the left-half of Table 8 suggest that a significant portion of bid-ask spread commonality documented in the literature can be explained by the comovement

[10] We also conduct our empirical test about limit order book commonality and overall stock market liquidity commonality, measured by dollar-quoted spread, and obtain similar results.

Table 7

Correlation between overall stock market commonality and limit order book commonality

This table shows the Pearson correlations between the commonality in the overall stock market liquidity and the limit order book commonality. The overall stock market liquidity is measured by the proportional quoted bid-ask spread. The liquidity provided by the limit order book is measured by limit order book cost-to-trade and dispersion measures. We use two proxies to measure the commonality in liquidity. In Panel A, the commonality in liquidity is measured by beta, which is the estimated coefficient on the concurrent market aggregate liquidity in the liquidity commonality regression described by Equation (4). Panel B presents the correlations using the commonality regression adjusted R^2 as a measure of commonality in liquidity. The *p*-values are shown in the parentheses.

	LOB dispersion (5 quotes)	LOB dispersion (10 quotes)	LOB cost-to-trade (1%)	LOB cost-to-trade (2%)	Quoted bid-ask spread (%)
Panel A: Beta					
LOB dispersion (5 quotes)	1.000	0.682	0.456	0.330	0.341
		(0.00)	(0.00)	(0.00)	(0.00)
LOB dispersion (10 quotes)		1.000	0.398	0.319	0.215
			(0.00)	(0.00)	(0.00)
LOB cost-to-trade (1%)			1.000	0.597	0.266
				(0.00)	(0.00)
LOB cost-to-trade (2%)				1.000	0.181
					(0.00)
Quoted bid-ask spread (%)					1.000
Panel B: Adjusted R^2					
LOB dispersion (5 quotes)	1.000	0.715	0.370	0.131	0.296
		(0.00)	(0.00)	(0.00)	(0.00)
LOB dispersion (10 quotes)		1.000	0.364	0.158	0.252
			(0.00)	(0.00)	(0.00)
LOB cost-to-trade (1%)			1.000	0.451	0.256
				(0.00)	(0.00)
LOB cost-to-trade (2%)				1.000	0.133
					(0.00)
Quoted bid-ask spread (%)					1.000

of the liquidity provided by the limit order book. For example, a 1% increase in the market aggregate limit order book cost-to-trade measure, based on 1% of the daily volume, will lead to a 0.32% increase in the proportional quoted bid-ask spread, and the coefficient estimate is highly statistically significant after the cross-equation correlation adjustment. Using other limit order book liquidity measures produces similar results.

In the second approach, the change in the market aggregate limit order book liquidity measure is orthogonalized on the market-level spread change instead. Then we regress the change in stock-level spread on the lead, lag, and concurrent values of the market-level spread change (DL_M) and the orthogonalized change in the market

Table 8

Bid-ask spread and limit order book liquidity

Daily percent changes in individual stock i's proportional quoted spread are regressed on daily percent changes in the market aggregate limit order book liquidity measures and the market-level spread percent changes. Two orthogonalization methods are used. In Method I, the market aggregate spread is orthogonalized on the market limit order book liquidity. In Method II, the market limit order book liquidity is orthogonalized on the market bid-ask spread. Control variables are defined in the same way as above. Cross-sectional statistics of time series regression coefficient estimates are reported with t-statistics adjusted for cross-equation correlation in parentheses. The coefficient estimates for the control variables are not reported for simplicity.

		Method I: The market average spread is orthogonalized on the market average limit order book liquidity measures				Method II: The market average limit order book liquidity measures are orthogonalized on the market average spread			
		Limit order book dispersion		Limit order book cost-to-trade		Limit order book dispersion		Limit order book cost-to-trade	
		Best 5 quotes	Best 10 quotes	1%	2%	Best 5 quotes	Best 10 quotes	1%	2%
Market average limit order book liquidity measures	Concurrent								
	Mean	0.275***	0.223***	0.322***	0.243***	0.045***	0.025	0.059***	0.031*
	(t-statistics)	(*24.35*)	(*15.38*)	(*24.96*)	(*14.13*)	(*3.57*)	(*1.62*)	(*4.03*)	(*1.75*)
	Median	0.257	0.208	0.308	0.228	0.046	0.025	0.061	0.026
	% positive	93.00%	87.56%	88.20%	86.20%	60.54%	56.85%	62.97%	54.71%
	% positive significant	56.27%	37.32%	57.05%	30.52%	9.82%	6.22%	10.98%	6.32%
	Sum								
	Mean	0.273	0.226	0.308	0.230	0.023	0.014	0.015	0.002
	Median	0.255	0.225	0.304	0.237	0.025	0.025	0.025	0.008
Market average spread	Concurrent								
	Mean	0.918***	0.951***	0.912***	0.951***	0.969***	0.967***	0.972***	0.968***
	(t-statistics)	(*29.14*)	(*31.39*)	(*30.00*)	(*31.70*)	(*34.97*)	(*33.69*)	(*36.52*)	(*33.97*)
	Median	0.897	0.933	0.892	0.930	0.944	0.940	0.944	0.943
	% positive	96.11%	96.40%	95.53%	96.11%	96.79%	96.70%	96.60%	96.70%
	% positive significant	69.19%	74.15%	68.42%	74.64%	75.80%	75.80%	76.48%	76.48%
	Sum								
	Mean	0.998	1.013	1.019	1.026	1.021	1.021	1.034	1.026
	Median	0.969	0.983	0.978	0.979	0.987	0.983	0.995	0.995
	Adjusted R^2	6.87%	6.82%	6.97%	6.89%	6.87%	6.82%	6.97%	6.89%

*,*** indicate statistical significance at the 0.10 and 0.01 level, respectively.

aggregate limit order book liquidity (DL_{OLOBM}), as well as the same control variables.

$$\begin{aligned} DSpread_{i,t} = {} & \alpha_i + \beta^1_{M,i} DL_{M,i,t} + \beta^2_{M,i} DL_{M,i,t-1} + \beta^3_{M,i} DL_{M,i,t+1} \\ & + \beta^1_{OLOBM,i} DL_{OLOBM,i,t} + \beta^2_{OLOBM,i} DL_{OLOBM,i,t-1} \\ & + \beta^3_{OLOBM,i} DL_{OLOBM,i,t+1} + \gamma_i^1 R_{M,t} + \gamma_i^2 R_{M,t-1} \\ & + \gamma_i^3 R_{M,t+1} + \delta_i DV_{i,t} + \varepsilon_{i,t}. \end{aligned} \tag{11}$$

Since limit order traders contribute to the overall stock market liquidity, the relation between the bid-ask spread and the limit order book liquidity could be captured by both β_M and β_{OLOBM}. In other words, the coefficient estimate on the orthogonalized market aggregate limit order book liquidity change (β_{OLOBM}) should be less significant than the coefficient estimate on the unorthogonalized one (β_{LOBM}) from Equation (10) above. In the right-half of Table 8, we find some statistical significance of the coefficient estimates on the orthogonalized market aggregate limit order book liquidity change, but the magnitude of these estimates decrease, as we discussed earlier.

Overall, our results show that the comovement of liquidity provided by the limit order book is able to explain some portion of the overall stock market liquidity commonality. Thus, we provide one more possible source of liquidity commonality in the stock market, from the perspective of the common behavior of limit order traders.

6. Conclusion

The limit order book consists of an essential source of liquidity in the stock market. We examine whether the liquidity provided by an individual stock's limit order book comoves with that of the market aggregate limit order book. Our study includes more than 1,000 NYSE-listed ordinary stocks, in the calendar year of 2003. To the best of our knowledge, this is the first time anyone has examined the existence of limit order book commonality with such a large and comprehensive sample coverage. The liquidity provided by the limit order book is measured by the limit order book dispersion and cost-to-trade measures. For both measures, we find that individual stock's limit order book liquidity comoves significantly with the market-average of these liquidity measures. Such comovement extends beyond the market level, that is, we also find significant comovement with the industry-specific component.

An important feature that differentiates our study from the previous liquidity commonality studies is that we separate the liquidity provided by the limit order book into inside and outside liquidity, depending on whether the limit order quote is near to or far away from the midquote. Our results show that inside liquidity provided by the limit order book exhibits much stronger commonality than outside liquidity. Further analysis suggests that inside liquidity is influenced mainly by market volatility, while outside liquidity is more likely to respond to idiosyncratic volatility. The difference in the impacts of market and idiosyncratic volatilities on inside and outside liquidity provides a natural explanation for the dissimilarity in their commonality pattern.

Based on the evidence of comovement in the limit order book liquidity, we further examine whether the limit order book commonality is capable of explaining the commonality in the overall stock market liquidity, measured by the bid-ask spread. We regress the change in stock spreads on the changes in the market-level spread and in the market aggregate limit order book liquidity measures. Our results suggest that some portion of the overall stock market liquidity commonality can be explained by the comovement of liquidity provided by the limit order book.

A fruitful future research venue would be to examine how the inside and outside liquidity, and their commonality, are priced in stock market, provided a longer sample period of order-level data is available.

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