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HOW LIQUID ARE MARKETS: AN APPLICATION TO STOCK MARKETS

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Liquidity is key to financial markets because its lack implies important consequences in terms of market price dynamics or market information revelation. For example, Easley *and al.* (1996) link information based trading and liquidity indicator (quoted spread). They show that the risk of information based trading and large quoted spreads are decreasing for the most liquid stocks. More generally, the liquidity of a market is a necessary condition for its smooth functioning. Most financial activities strongly depend on liquidity, like financial institution risk management and financial asset valuation. Recently for example, international accounting authorities (FASB[1], the SEC[2] in September 2008 and IASB[3] in October 2008) as well as national ones (AMF[4], CNC[5], ACAM[6] and Commission Bancaire in October 2008) have allowed financial institutions to re-classify their assets and to stop marking-to-market when an asset's market has dried-up. Furthermore, liquidity problems that face financial institutions have an impact on the monetary stance through the management of funding liquidity. Finally, during all financial crises, like in the current one, a rapid dry-up of one or more markets has caused very high price volatility which in turn has strengthened the liquidity scarcity of some markets.

The analysis of market liquidity is of first importance. However, liquidity remains an elusive concept and determining whether a market is active/liquid or not is not straightforward (see Goyenko *and al.* (2009)). To gauge market liquidity, one first needs to define it before proposing accurate measures. For example, the SEC and FASB advice to rely on criteria such as bid-ask spreads and the number of counterparts. Now, how do those two market characteristics account for liquidity?

A market is said to be liquid if, at any point in time, investors can trade quickly (*immediacy*), at fair price and low cost (*tightness*), a large amount of shares with a small impact on prices (*depth*)[7]. Moreover, in the absence of new information, any price error must be quickly eliminated (*resiliency*). This rather detailed definition, although imprecise, has the advantage of highlighting some dimensions of liquidity. First of all, there is a time-dimension at two levels. On the one hand, investors should be able to trade rapidly and to find instantaneously a counterpart to prevent them from facing a price reversal risk due to possible new information arrivals. On the other one, market efficiency imposes that any market price change, that is not a consequence of an information arrival, should rapidly vanish. The second dimension is linked to volume: at any instant in time, there must be enough bids and offers to satisfy investors needs, such as liquidity needs or the wish to take advantage of an information concerning the assets. Finally, liquidity has a price-dimension: assets should be cheaply traded at a fair price and these trades should have small impacts on prices. From this multidimensional definition, we clearly understand how difficult it is to propose a liquidity measure that simultaneously accounts for all these interdependent characteristics at once. One possible solution is to jointly analyze several liquidity measures that account for one aspect at a time.

In this paper, we consider and present four categories of liquidity measures: immediacy, depth, tightness and resiliency. Considering four international financial institution stocks, recently impacted by the crisis, we show that these measures are not substitutes and have to be jointly analyzed in order to get a reliable picture of stock market liquidity. These measures can also be applied to any other market such as bonds, foreign exchange. Some of the measures require a large amount of information on transactions, which is usually disclosed on organized markets. However, some assets are traded over the counter (OTC) where transactions are not centralized and the information is not disclosed. In that case, it seems rather difficult to give an objective measure and thus a complete picture of the degree of activity or liquidity.

I. LIQUIDITY MEASURES

Several types of indicators account for several market liquidity characteristics. We propose a liquidity indicator classification based on four standard market dimensions as *immediacy*, *depth*, *tightness and resiliency*. In each of these categories we discuss several liquidity indicators commonly used in the literature.

I.1. IMMEDIACY

A first strand of liquidity indicators considers market immediacy defined as the ability of agents to quickly trade. The more liquid a market, the faster a buy or sell posted order leads to a transaction.

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A first indicator is the average **duration between transactions.** Another possibility is to define immediacy as the necessary **delay of time to observe an increment *x* of some quantities** as traded volumes (v) or number of trades (n). In general this duration τ at time t_i is defined as:

$$\tau(t_i, x) = \inf\{\tau : X_{t_{i+\tau}} \geq X_{t_i} + x\} \qquad (1)$$

where X represents any indicator of interest as volume or number of transactions and *x* is one realization of the variable of interest. For example, the duration between two trades is $\tau(t_i;\ n = 1)$ or the duration to obtain 100 more traded volume is $\tau(t_i;\ v = 100)$. This is shown to be varying during the day, and depends on market conditions (Gouriéroux *et al.* (1999)). This is related to the trade intensity or the **number of trades for a given interval** of time that allows discriminating between calm and rush trading periods. As we will further see, this need for immediacy may translate into higher transaction costs reflected, for example, in bid-ask spreads.

Another indicator is the average **duration between the last posted quote and the transaction.** This exerts the attractiveness of posted quotes with potential discount on prices to rapidly sell or buy some assets. In parallel, another indicator related to this attractiveness of posted quotes is the **number of quote revisions (arrivals) before a transaction** occurs. This is clearly linked to the price discovery process of the asset leading to a matching more or less efficient and rapid between sellers and buyers.

I.2. DEPTH

Market depth characterized the ability to trade large volumes with little (or no) impact on prices. This aspect of liquidity is usually captured by measures related to the traded and offered volumes in the market. The total volume of transactions is one simple indicator of liquidity as used in Easley *and al.* (1994).

Considering V_i the traded volume for transaction i; the total volume of transaction T_{Vt} at frequency (that may be the hour, the day, the week or any other interval of time) is[8]

$$TV_t = \sum_{i=1}^{N_t} V_{i,t} \qquad (2)$$

The idea beyond traded volume is that the market is liquid if it is able to absorb high transaction volumes. It is the natural view of market liquidity.

Some other volume related indicators are also of interest. For example, the **average traded volume per transaction** may monitor a liquidity risk in the market, with investors splitting their orders over an interval of time instead of asking for the whole volume at once:

$$AV_t = \frac{1}{N_t}\sum_{i=1}^{N_t} V_{i,t} \qquad (3)$$

with N_t the number of transactions during period t.

In this strand, the **turnover rate** is also an interesting indicator to monitor trading activity:

$$T_t = \sum_{i=1}^{N_t} \frac{V_{i,t}}{K} \qquad (4)$$

where K is the total volume of outstanding shares. However, the main drawback of these indicators is that volumes are not always available in the database. For this reason, some other related indicators of liquidity as the **number of trades** N_t is widely used as a proxy of market trade intensity.

Another indicator of market depth is the **unitary price to buy or sell *v* share immediately**.

On automated markets, if $v = 1$, we get the order book depth, *i.e.* the quantity at the bid or ask. In general, we get a volume weighted average price (see Gouriéroux, Le Fol and Meyer (1998)).

A last indicator in market depth is related to the potential imbalances between market buy and market sell sides. To consider this issue, we consider the **order flow**. The orientation of the market contains some information and the order flow statistic translates the potential imbalances in trade dynamics. This usually reflects some liquidity problems with for example a majority of sellers (or buyers). The most widely used methodology is the one by Lee and Ready (1991). They compare the position of the transaction price relative to the midquote. On the one side, if the price is higher than the midquote, the trade is buy initiated. On the other side, if the price is lower than the midquote, the trade is sell initiated. The order flow for an interval of time index by t with N_t transactions indexed by i is then calculated as follows.

$$OF_t = \frac{1}{N_t}\sum_{i=1}^{N_t} Q_{i,t} \qquad (5)$$

with $Q_{i,t} = 1$ if the order is buy initiated (*i.e.* the transaction price is higher than the midquote) and $Q_{i,t} = -1$ if the order is sell initiated (*i.e.* the transaction price is lower than the midquote). If the market is perfectly balanced the order flow is null. If it is perfectly buy oriented or sell oriented it respectively reaches the bounds of + 1 and – 1. Some other methodologies have been used in the literature to define the order flow, notably to circumvent the main problem of some OTC markets where the transaction price is not available. For example, these techniques use the relative variations of bid-ask spreads to compute the order flow (see Idier and Nardelli (2008) for the overnight euro market rate). Finally, a last indicator, introduced by Engle and Lange (2001) is the **VNET**. This indicator considers both the traded volumes and the imbalances between buy and sell orders for a given variation of price.

To analyze the market depth it is also possible (when data are available) to analyze the characteristics of the market order book and notably what is called the **market order book slope**. This last considers the heterogeneity in prices awaiting beyond the best price limit. If prices are very close to each other in the order book (at both the buy and sell side) the price variation induced by transaction would be limited. However, considering a steep slope in the order book with huge gaps between awaiting offered prices, the price impact on the market would be strong.

I.3. TIGHTNESS

Market tightness represents transaction costs and is mainly related to the difference between the ask price (for buy initiated trades) and bid price (for sell initiated trade). This difference is called the **bid-ask spread**. The literature on bid-ask spread is large in trying to decompose the size of the spread in several components: information asymmetry, trading cost and inventory cost or cost for immediacy (Roll (1984), Glosten (1992), Glosten and Harris (1987), George *and al.* (1992), Huang and Stoll (1997), Mc Inish *and al.* (1992)).

First of all, market spreads represent transaction costs on the buy side (ask price) or on the sell side (bid price). The wider the spread, the higher the transaction costs. This cost is positively correlated with information asymmetries, direct trading cost (as the tick size on the market), inventory constraints or the need for immediacy of traders.

Three market spread measures are usually used. The first one is the quoted spread for transaction i as

$$S_{i,t} = p_{i,t}^{Ask} - p_{i,t}^{Bid} \qquad (6)$$

One drawback of this measure is that the spread is usually directly linked to the level of price, so that spreads are wider for stocks with higher prices. This usually comes from the size of the tick on the market. One way to circumvent this problem is to use a **relative spread** measure as

$$S_{i,t}^{relative} = \frac{S_{i,t}}{M_{i,t}} \qquad (7)$$

where $M_{i,t} = \left[\frac{p_i^{Ask} + p_i^{Bid}}{2}\right]$; *i.e.* the midpoint between the ask and bid prices. However, the occurring trade does not always match exactly the bid or ask price but can be in between. To respond to that issue it is used the **effective spread** as

$$S_{i,t}^{effective} = 2Q_{i,t} \times \left[p_{i,t} - M_{i,t}\right] \qquad (8)$$

where $p_{i,t}$ is the prevailing transaction price and $Q_{i,t} = 1$ if $p_{i,t} > M_{i,t}$ so that the transaction is buy initiated, and $Q_{i,t} = -1$ if $p_{i,t} < M_{i,t}$ *i.e.* the transaction is sell initiated.

Finally, under the assumption that information revealed by transaction i is considered in prices of transaction $i + 1$. Therefore, the midquote of transaction $i + 1$ is supposed to reveal the true value of the asset prevailing at transaction i. Then, the **realized spread** based on the supposed true value of the asset is

$$S_{i,t}^{realized} = 2Q_{i,t} \times \left[p_{i,t} - M_{i+1,t}\right] \qquad (9)$$

Note that this measure is not obviously positive since nothing can guarantee that the transaction price is higher or lower than the next midquote. This last measure illustrates the information asymmetries between traders that are incorporated in quoted prices. This is reflected by the difference in the effective spread, based on public information contained in $M_{i,t}$. The realized spread translates the private information component of the spread by considering the true value of the asset, assumed to be incorporated in the next midquote $M_{i+1,t}$ assuming the efficient market hypothesis.

I.4. RESILIENCY

The ability to trade a large volume without long lasting price impact on the price determines the market resiliency: this is usually captured by measures of volatility, or so-called market impact cost measures. In an illiquid market, a large transaction volume generates more substantial price variations than for a liquid market. This phenomenon can be characterized by measures of price variations or by measures constructed from the order book. Furthermore, the market impact cost measures assesses the market's ability to absorb orders without launching large price variations compared to the "sell" price (bid) and "buy" price (ask).

A first indicator is price volatility and notably **realized volatility**. Since the seminal paper of Merton (1980) realized volatility has been widely used in the literature. Typically, it uses the intraday returns of an asset to calculate daily volatility measures. There exist several realized volatility estimators (see Avouyi-Dovi and Idier (2009)) as for example the Merton estimator defined as the sum of squared intra period returns or the more recent bipower variations (as BPV) from the work of Barndorff-Nielsen and Shephard (2003). To compute the BPV, let consider a partition ψ of the day retaining the last transaction of equal subintervals of time (typically 5 or 15 minutes). Then, the day t volatility estimator is defined as

$$BPV_t = \sum_{i \in \Psi} \left| r_{i,t} \times r_{i-1,t} \right| \qquad (10)$$

where r_i and r_{i-1} are subsequent returns for the considered subintervals of day t (see Andersen *and al.* (2003), Barndorff-Nielsen and Shephard (2004), Barndorff-Nielsen *and al.* (2006)). High volatility means that some transactions have launched some periods of disturbance in the markets which are more or less resilient.

Some other methodologies propose to characterize the **transitory versus the permanent effects of price impact costs**. These indicators are derived from the microstructure model of Glosten and Harris (1988) and used for example in Pastor and Stambaugh (2003), Sadka (2006) or Korajczyk and Sadka (2008). In the latter the price variation is characterized by four factors: the unexpected nature of the trade (buy or sell order), the unexpected traded volume, the market orientation changes (buy or sell dynamics) and the observed variations in bought or sold volumes. While the two first factors capture some permanent impact on the price variations, the two last factors consider the transitory price impact cost components (see the aforementioned papers for econometric setup details).

Another indicator in this market dynamics analysis strand is the **variation in bid-ask spreads after a transaction**. This measure is based on the prices and quotes but more in a dynamic way. Here, we analyze the quote movements relative to the previous transaction. This is defined as

$$\Delta S_{i,t} = \frac{S_{i+1,t} - S_{i,t}}{S_{i,t}} \quad (11)$$

for transaction i. $S_{i+1,t}$ is the spread that instantaneously follows transaction i and $S_{i,t}$ is the spread prevailing for transaction i. This relative variation reflects the impact of a transaction on market quotes. The higher this variation, the less liquid the market. This is directly linked to the tightness and depth of the market and implies subsequent intervals of time without trade and/or with huge price variations for the following trades. This spread variation measure induced by transaction i may be applied to all aforementioned spread measures (relative, effective or realized).

II. EMPIRICAL APPLICATION

In this section, we propose an empirical application based on a selected set of liquidity measures each of them representing one of the four categories (immediacy, depth, tightness, and resiliency) presented above. We consider the stock of four international financial institutions but, of course, these measures of liquidity could be applied to other financial assets and/or markets. First, we illustrate the lack of substitutability of these measures by comparing their correlations. Second, we analyze their historical evolutions.

II.1. DATA AND SELECTED MEASURES

Our dataset consists in transactions and quotes for four financial institutions securities recently impacted by the crisis: Lehman Brothers (NYSE), AIG (NYSE), Dexia (Euronext Paris) and BNP-Paribas (Euronext Paris) from Reuters Data Tick History. The sample size for each of the companies is provided in appendix A. The available information for each security consists in: all the quotes (buy and sell orders), prices and volumes of transactions, date and time stamps. Therefore, our dataset information is sufficiently rich to compute all the aforementioned measures of liquidity. In this section, we focus on four measures that correspond to one of the four categories presented in the previous section:

- duration between two transactions (immediacy): $\tau(t_i, n = 1)$;
- average traded volume per transaction (depth): $AV_{i,t}$;
- relative bid-ask spread (tightness): $S_{i,t}^{relative}$;
- variation in bid-ask spread after a transaction (resiliency): $\Delta S_{i,t}$.

II.2. NON SUBSTITUTABILITY OF LIQUIDITY MEASURES

The measures considered in this paper are related to one aspect of liquidity, and are not a priori perfect substitutes. The aim of this section is to illustrate this fact. For that purpose, we compare the correlation coefficients between the four liquidity measures for the AIG stock. Again, because all the liquidity measures are only proxies of a multidimensional concept, there is no reason that they behave similarly over time neither that they correlate in a stable way. More particularly, one may expect that during period of troubles correlations between measures could change. In order to address this point, we consider rolling correlations over a window of 12 months (see Figure 1).

Two facts are striking. First, correlations can be positive or negative. More particularly, they are often far from one (in absolute value). This result confirms the non substitutability of liquidity measures and the heterogeneity of information provided by each indicator depending on market situations. Second, these correlations are not stable. For example, the correlation between the relative spread and the delay between two transactions becomes negative between September 2007 and September 2008. This would indicate that even if the bid-ask spread is increasing, the delay between two transactions is decreasing which clearly shows a market liquidity problem. However, looking at the trade frequency may give a picture of a liquidity improvement.

In this sense, liquidity measures should be considered as complements instead of substitutes. Therefore a reliable diagnostic in terms of liquidity must be based on a set of liquidity measures and cannot only rely on one of them. In the next section, we complete our analysis by a visual inspection of monthly averages of our liquidity measures.

II.3. HISTORICAL EVOLUTION OF LIQUIDITY MEASURES SINCE 2005

How has liquidity evolved over a given period is a key issue that should be scrutinized with a set of measures. For instance a decrease in the duration between transactions can lead to two opposite conclusions in terms of liquidity:

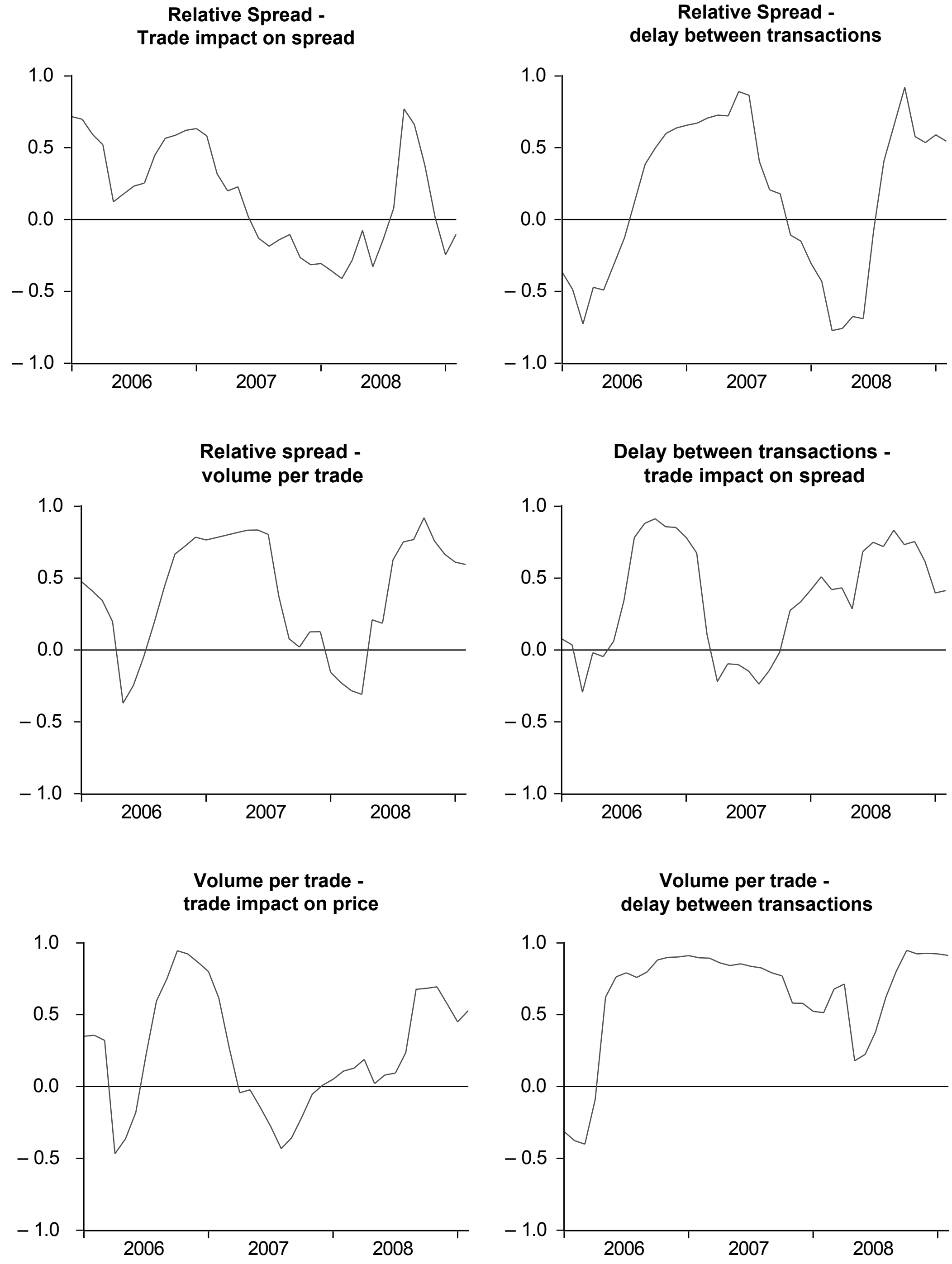
- on the one hand, a liquidity improvement due to an increase of the number of trades,
- on the other hand, an increase in the splitting of "big transactions" into several "smaller trans- actions". This kind of behavior reflects fears of investors regarding a potential scarcity of liquidity.

In the former case, we should observe a decrease in the duration between two trades and an increase (or at least no change) in the average traded volume per trade. In contrast, in the latter case, we should also observe a decrease in both measures. This example illustrates that conclusions regarding evolution of the liquidity of a market must be based on the joint analysis of a set of indicators in order to prevent misinterpretations.

We report in Figure 2, the historical evolution of liquidity indicators from January 2005 to January 2009 for AIG, Lehman Brothers, BNP-Paribas and Dexia. In addition table 1 provides sample correlations.

- For AIG (and Lehman), the joint evolution of the relative spread and the delay between two trades points that liquidity conditions in the market have probably worsen in the summer 2008 (and spring 2008). In addition, the decreasing trends of the volume per trade and duration between consecutive trades

Figure 1. 12 month rolling window correlations between liquidity indicator (AIG stock)



observed at the beginning of the sample indicate that investors probably began to fear a deterioration in the liquidity conditions. As a consequence, they intensify their splitting scheme. Note that, if our analysis was based only on the relative trade impact on spread our conclusions would be different as this indicator does not signal any deterioration of liquidity conditions over the whole period.

■ For Dexia, the joint evolution of the four measures confirms a deterioration of liquidity condition starting in fall 2008.

■ Finally, for BNP-Paribas, the relative spreads and the delay between two trades are in favor of stable liquidity conditions over the period. Note however that, the increasing trend in the relative trade impact on spread and the decreasing volume per trade, observed jointly

Figure 2

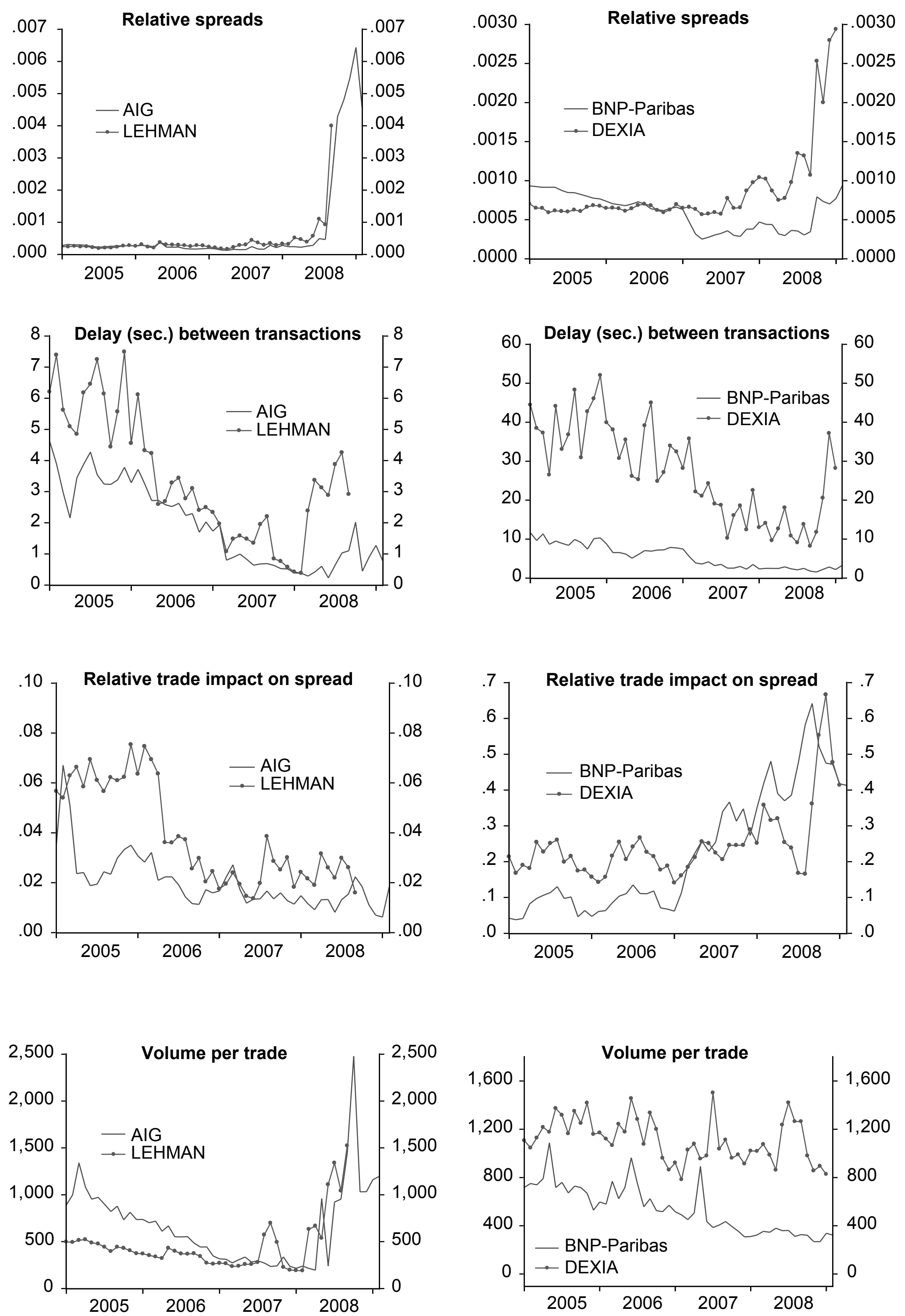

Relative spreads
AIG
LEHMAN
.000
.001
.002
.003
.004
.005
.006
.007
2005
2006
2007
2008
Relative spreads
BNP-Paribas
DEXIA
.0000
.0005
.0010
.0015
.0020
.0025
.0030
2005
2006
2007
2008
Delay (sec.) between transactions
AIG
LEHMAN
0
1
2
3
4
5
6
7
8
2005
2006
2007
2008
Delay (sec.) between transactions
BNP-Paribas
DEXIA
0
10
20
30
40
50
60
2005
2006
2007
2008
Relative trade impact on spread
AIG
LEHMAN
.00
.02
.04
.06
.08
.10
2005
2006
2007
2008
Relative trade impact on spread
BNP-Paribas
DEXIA
.0
.1
.2
.3
.4
.5
.6
.7
2005
2006
2007
2008
Volume per trade
AIG
LEHMAN
0
500
1,000
1,500
2,000
2,500
2005
2006
2007
2008
Volume per trade
BNP-Paribas
DEXIA
0
400
800
1,200
1,600
2005
2006
2007
2008

Table 1. Sample correlations between liquidity indicators (01/2005 – 01/2009)

	$\tau(t_i, n=1)$	$AV_{i,t}$	$S_{i,t}^{relative}$	$\Delta S_{i,t}$
$\tau(t_i, n=1)$	1	0.198	– 0.133	0.659
$AV_{i,t}$		1	0.699	0.122
$S_{i,t}^{relative}$			1	– 0.268
$\Delta S_{i,t}$				1

with a declining delay between two trades, indicate that the fear of a liquidity scarcity increasing in the market, at least since the beginning of 2007.

III. USES AND CONCLUSIONS

As seen in the several categories of aforementioned indicators, liquidity may not be solely characterized by a unique indicator. Again, liquidity has four complementary dimensions which are not substitutable. However, the choice of any liquidity indicator is not free in practice. First, datasets may not provide all the needed information to characterize market liquidity on its multidimensional sides (immediacy, tightness, depth and resiliency). For example, data related to traded volumes are not always available at an intraday frequency, so that depth can hardly be computed. This data availability is also highly dependent on market organization. For example, liquidity of an over the counter market cannot so easily be assessed due to the lack of transparency of such markets.

Second, if we assume that all the needed information is available, there is no clear method to especially choose one of these liquidity proxies. One possible solution to summarize the several sides of liquidity indicators is to consider factor models to extract the liquidity common component of all these related indicators. Factor models can also be applied not solely across indicators, but also across assets to determine the liquidity of the market as a whole (Korajczyk and Sadka (2008)). However, the results are sometimes disappointing due to the high heterogeneity of the indicators.

This comes from two facts. First, these indicators are complementary and not substitutable as shown in our application on four stocks: some of them represent the costs related to intermediary activities, from information asymmetries, price disruptions etc. Second, these indicators may depend on market organization (over the counter market, order driven market, price driven market) or rule of exchanges (tick size, primary dealer competition) or market segment (durable good industry vs. financial industry for example). One possible solution would be to extract factors by liquidity dimension. In this way, each factor would represent one market liquidity aspect.

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1 Financial Accounting Standards Board.
2 Securities and Exchange Commission.
3 International Accounting Standards Board (IASB).
4 Autorité des marchés financiers.
5 Conseil national de la comptabilité.
6 Autorité de contrôle des assurances et des mutuelles.
7 First defined in Black (1971), it has been taken up in the microstructure literature since then and even by some financial institutions more recently: BIS (1999), IMF(2004).
8 For details see Gouriéroux, Jasiak and Le Fol (1999) or Bauwens and Giot (2001).

Appendix A

Sample descriptions

	Sample dates
AIG	from January 1st, 2005 to February 28th, 2009
Lehman	from January 1st, 2005 to September 15th, 2008
BNP-Paribas	from January 1st, 2005 to January 15th, 2009
Dexia	from January 1st, 2005 to January 15th, 2009

Data source: Reuters data tick history

Appendix B

Summary table for main liquidity statistics (for notations please refer to the main text)

	Statistics	Formula
Immediacy	Transaction duration	$\tau(t_i, n = 1) = \inf\{\tau : N_{t_{i+\tau}} \geq N_{t_i} + 1\}$
	Volume duration	$\tau(t_i, v = 1) = \inf\{\tau : V_{t_{i+\tau}} \geq V_{t_i} + 1\}$
Depth	Total volume	$TV_t = \sum_{i=1}^{N_t} V_{i,t}$
	Average volume	$AV_t = \frac{1}{N_t} \sum_{i=1}^{N_t} V_{i,t}$
	Turnover	$T_t = \sum_{i=1}^{N_t} \frac{V_{i,t}}{K}$
	Order Flow	$OF_t = \frac{1}{N_t} \sum_{i=1}^{N_t} Q_{i,t}$
Tightness	Relative spread	$S_{i,t}^{relative} = 2\frac{p_{i,t}^{Ask} - p_{i,t}^{Bid}}{p_{i,t}^{Ask} + p_{i,t}^{Bid}}$
	Realized spread	$S_{i,t}^{realized} = 2Q_{i,t} \times \left[p_{i,t} - \frac{p_{i,t+1}^{Ask} + p_{i,t+1}^{Bid}}{2}\right]$
Resiliency	Bipower variations	$BPV_t = \sum_{i \in \Psi} \lvert r_{i,t} \times r_{i-1,t} \rvert$
	Realized volatility	$RV_t = \sum_{i \in \Psi} r_{i,t}^2$
	Trade impact on spread	$\Delta S_{i,t} = \frac{S_{i+1,t} - S_{i,t}}{S_{i,t}}$

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