Intraday pattern in bid-ask spreads and its power-law relaxation for Chinese A-share stocks

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Abstract

We use high-frequency data of 1364 Chinese A-share stocks traded on the Shanghai Stock Exchange and Shenzhen Stock Exchange to investigate the intraday patterns in the bid-ask spreads. The daily periodicity in the spread time series is confirmed by Lomb analysis and the intraday bid-ask spreads are found to exhibit $L$-shaped pattern with idiosyncratic fine structure. The intraday spread of individual stocks relaxes as a power law within the first hour of the continuous double auction from 9:30AM to 10:30AM with exponents $\beta_{\text{SHSE}} = 0.20 \pm 0.067$ for the Shanghai market and $\beta_{\text{SZSE}} = 0.19 \pm 0.069$ for the Shenzhen market. The power-law relaxation exponent $\beta$ of individual stocks is roughly normally distributed. There is evidence showing that the accumulation of information widening the spread is an endogenous process.

Key words: Econophysics; Bid-ask spreads; Intraday pattern; Relaxation dynamics; Chinese stocks; Power law
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1 Introduction

In most modern financial markets, the intraday pattern exists extensively in many financial variables \cite{123}, including the bid-ask spread \cite{4}. The periodic pattern has significance impact on the detection and understanding of long memory in time series \cite{5}. To the best of our knowledge, detailed investigation of intraday patterns in the bid-ask spreads of Chinese stocks is rare \cite{6}.

Empirical studies have examined the intraday pattern in bid-ask spreads for various types of stock markets. It has been documented that the intraday width of bid-ask spreads for New York Stock Exchange (NYSE) stocks follows a U-shaped pattern, where the spreads are the widest immediately after the opening of the market and right before the closure \cite{784}. Some researchers studied two samples of National Association of Securities Dealers Automated Quotation (NASDAQ) stocks and related the results to the institutional features of the dealer market \cite{9}. They found that, in contrast to the U-shaped pattern for NYSE stocks, the bid-ask spreads for NASDAQ securities are relatively stable throughout the day but narrow significantly during the final hour of trading. These results are similar to the declining intraday spreads for firms on the London Stock Exchange during mandatory trading hours \cite{10}.

Despite of the extreme importance of the bid-ask spreads in the study of market microstructure, the intraday pattern in spreads of Chinese stocks has not attracted much attention. The Chinese stock market operates as an order-driven system, which again account for only a small part in literature of microstructure theory. The Chinese stocks are traded on the Shanghai Stock Exchange (SHSE) and the Shenzhen Stock Exchange (SZSE). The market opens at 9:15AM with call auctions till 9:25AM and then enters a five-minute cooling period. The stocks are traded based on continuous double auction from 9:30AM to 11:30AM and from 13:00PM to 15:00PM. The trading pauses from 11:30AM to 13:00PM. The intraday spreads of Chinese stocks thus exhibit different fine structures.

In this work, we investigate the intraday pattern in bid-ask spreads of 1364 Chinese A-share stocks\footnote{A shares are common stocks issued by mainland Chinese companies, subscribed and traded in Chinese RMB, listed in mainland Chinese stock exchanges, bought and sold by Chinese nationals. A-share market was launched in 1990.}. The data sets are described in Sec. 2. We confirm in Sec. 3.1 that the spread time series has a daily periodicity and show the intraday patterns in bid-ask spreads in Sec. 3.2. The wide bid-ask spread after the cooling period implies the cumulation of personal interpretation of public and private information received before continuous auction. In the framework of complex systems theory, the relaxation dynamics of spread contain crucial information about the cumulation process during the cooling period. We thus investigate in detail the relaxation behavior of the spreads when entering the continuous double auction in Sec. 4.
Section 5 summarizes and provides a brief discussion.

2 Data sets

2.1 Description and preprocessing of the raw data

We utilize a nice high-frequency database containing 829 stocks traded on the SHSE and 535 stocks on the SZSE in the Chinese A-share market covering the whole year of 2005. The data were recorded based on the market quotes disposed to all traders in every six to eight seconds, which are different from the ultra-high-frequency data reconstructed from the limit-order book. Each datum is time stamped to the nearest second at which one transaction occurs. Therefore, for each stock $i$, the raw data of interest contain two time series, $a_i(t)$ for the best ask prices and $b_i(t)$ for the best bid (or offer) prices, where $t$ is the unevenly spaced calendar time. There are totally 73,187,642 entries for the SHSE stocks and 48,697,722 for the SZSE stocks.

We adopt the following criteria to avoid possible recording errors. First, the bid price should not be larger than the ask price and the data at moment $t$ where $a_i(t) \leq b_i(t)$ are removed. Second, all the data in a given trading day are discarded if the trading frequency is anomalously low. Third, the data stamped with times outside the continuous double auction (9:30AM to 11:30AM and 13:00PM to 15:00PM) are eliminated. Fourth, we segment each trading day into eight 30-minute intervals. The whole data of a trading day are excluded in case any one of the eight intervals is empty such that the possible intraday pattern in the spread for the stock is reserved.

2.2 Constructing 30-second bid-ask spread

There are different definitions for the bid-ask spread in literature [11,12,13,14,15,16,17,18,19,20], which nevertheless do not ruin the possible intraday pattern in spread. The “point” definition of spread for stock $i$ at time $t$ is the difference between best bid and ask prices:

$$s_i(t) = a_i(t) - b_i(t).$$

We stress that $t$ is unevenly spaced calendar time. Each trading day is evenly divided into 480 time intervals with a length of 30 seconds. The 30-second spread is then defined as the average of the available spreads within each interval

$$S_i(t') = \langle s_i(t) \rangle, \quad t \in T(t')$$

(2)
where T(t′) is the t′-th 30-second time interval. For simplicity, S_i(t′) is set to be zero if there is no recorded data in T(t′) such that each trading day corresponds to 480 consecutive data points in the time series S_i(t′).

The market-averaged bid-ask spread is

\[ S(t') = \frac{1}{N(t')} \sum_{i \in \Phi(t')} S_i(t'), \]

where the set \( \Phi(t') = \{ j : S_j(t') \neq 0 \} \) and \( N(t') \) is the size of \( \Phi(t') \). Figure 1 shows two market-averaged time series of the 30-second bid-ask spreads for all A-shares on the SHSE and SZSE, respectively. We observe that the spread exhibits daily periodicity and declines during the continuous double auction.

Fig. 1. Parts of the market-averaged time series of the 30-second bid-ask spreads: (a) SHSE, (b) SZSE. Intraday pattern is clearly visible.

3 Characterizing intraday pattern in spread

3.1 The daily periodicity

As a first step, we attempt to confirm daily periodicity in spread time series observed in Fig. 1. The normalized Lomb power is used for this purpose \([21, 22, 23, 24, 25]\), which is equivalent to the conventional spectrum analysis for evenly sampled time series. The normalized Lomb power is defined as follows

\[ P_N(f) = \frac{1}{2\sigma^2} \left \{ \frac{\left[ \sum_j (y_j - \bar{y}) \cos \omega(t_j - \tau) \right]^2}{\sum_j \cos^2 \omega(t_j - \tau)} + \frac{\left[ \sum_j (y_j - \bar{y}) \sin \omega(t_j - \tau) \right]^2}{\sum_j \sin^2 \omega(t_j - \tau)} \right \}, \]

where \( y_j \) is the observed spread, \( \bar{y} \) is the mean spread, \( \omega \) is the angular frequency, and \( \tau \) is the phase shift.
where \( y = S \) is the 30-second spread time series of size \( N \), \( \omega = 2\pi f \), \( \bar{y} \) and \( \sigma \) are the mean and standard deviation of \( y \) (or \( S \)), and

\[
\tan(2\omega) = \frac{\sum_j \sin(2\omega t_j)}{\sum_j \cos(2\omega t_j)},
\]

which determines the parameter \( \tau \).

Figure 2 illustrates the Lomb periodograms of the bid-ask spread time series \( S(t') \) for the two Chinese stock markets. The highest Lomb peak in Fig. 2(a) for SHSE stocks has height \( P_N = 420.4 \) located at \( f = 0.002073 \), whose \( p \)-value is \( \ll 0.0001 \). This gives a period of \( 1/f = 482.4 \) data points corresponding approximately to one trading day. The highest Lomb peak in Fig. 2(b) for SZSE stocks has height \( P_N = 372.6 \) located at \( f = 0.002073 \), whose \( p \)-value is \( \ll 0.0001 \). This also gives a period of roughly one trading day.

A crucial feature observed in Fig. 2 is the presence of harmonic peaks evenly spaced, which provides further evidence for the presence of periodicity and strengthens its statistical significance. These harmonics peaks enable us to estimate the fundamental frequency alternatively in a more accurate manner [23,24,25]. The approach applies the simple relationship between the fundamental frequency \( f_0 \) and its harmonics \( f_n \)

\[
f_n = n \times f_0. \tag{6}
\]

According to Fig. 2 the values of \( f_n \) with \( n = 1, 2, \ldots, 23 \) are 0.002073, 0.004162, 0.006236, 0.00833, 0.01042, 0.01250, 0.01459, 0.01666, 0.01876, 0.02084, 0.02293, 0.02499, 0.02708, 0.02917, 0.03125, 0.03334, 0.03542, 0.03752, 0.03957, 0.04169, 0.04376, 0.04583, 0.04793 for the SHSE market averaged spreads, and 0.002073, 0.004162, 0.006251, 0.00833, 0.01042, 0.01250, 0.01459, 0.01667, 0.01875, 0.02084, 0.02293, 0.02501, 0.02709, 0.02919, 0.03127, 0.03335, 0.03542, 0.03751, 0.03960, 0.04165, 0.04376, 0.04584, 0.04791 for the SZSE market averaged spreads. In order to estimate as accurately as possible the numerical value of the fundamental frequency \( f_0 \), Fig. 3 plots the frequencies \( f_n \) of all the peaks found in Fig. 2 as a function of the peak sequence number \( n \). Least-squares linear regression of
the 23 harmonics gives \( f_0 = 0.0020840 \pm 0.0000003 \) for the SHSE case and \( f_0 = 0.0020837 \pm 0.0000003 \) for the SZSE case. These values are very close to the theoretic ansatz \( f = 1/480 \approx 0.0020833 \). We are thus able to conclude that there is evident daily periodicity in the market averaged spread \( S(t') \). This property holds for the spread \( S_i(t') \) of individual stocks.

![Graph showing determination of the fundamental frequency \( f_0 \) with a linear fit: the open circles are all peaks indicated in Fig. 2(a) and the open upward triangles are those peaks in Fig. 2(b). Excellent linear fits are obtained with the slopes \( f_0 = 0.0020840 \pm 0.0000003 \) (○) and \( 0.0020837 \pm 0.0000003 \) (△), close to the theoretical value \( f = 1/480 = 0.0020833 \). The solid line is the theoretical prediction \( f_n = n/480 \).

3.2 The intraday patterns

Based on the daily periodicity in \( S_i(t') \) and \( S(t') \), we are able to study the intraday patterns in the spread. Specifically, we average the spread with same intraday time over different trading days, which gives

\[
\overline{S}_i(\tau) = \frac{1}{D_i} \sum_{d=1}^{D_i} S_i(480(d-1) + \tau), \quad \tau = 1, \ldots, 480 
\]  

(7a)

for individual stock \( i \), where \( D_i \) is the number of trading days of stock \( i \), and

\[
\overline{S}(\tau) = \frac{1}{D} \sum_{d=1}^{D} S(480(d-1) + \tau), \quad \tau = 1, \ldots, 480 
\]  

(7b)

for market-average spread, where \( D = 239 \) for the SHSE and \( D = 240 \) for the SZSE.

Figure 4 shows the intraday pattern in the bid-ask spreads \( \overline{S}(\tau) \) for all the A-shares traded on the SHSE and the SZSE in the year 2005. It is observed that the bid-ask spreads exhibit \( L \)-shaped intraday pattern. In general, the spread is the largest
close to 0.04 CNY (Chinese Yuan) at the open of the continuous double auction and then declines fast to the average level of 0.015 CNY an hour later. Before the closing of the markets at 11:30AM, the spread increases slightly. When the markets reopen at 13:00PM, the spread is again wider than average, which offsets to the normal level in a few minutes. The markets close with a slight increase in the spread at 15:00PM. The situation for individual stocks is qualitatively similar, especially between 9:30AM and 10:30AM. This well established pattern allows us to investigate in detail the relaxation behavior of spreads during this time period.

Fig. 4. Intraday pattern in the bid-ask spreads for all the A-shares traded on the SHSE (a) and the SZSE (b) in the year 2005.

4 Power-law relaxation of intraday spreads

4.1 Power-law decay of intraday spreads $\overline{S}(\tau)$

Figure 5 shows the averaged intraday spread $\overline{S}(\tau)$ as a function of $\tau$ in double logarithmic coordinates for the SHSE and SZSE. We find that the spread $\overline{S}(\tau)$ decays roughly as a power law in the first hour from 9:30AM to 10:30AM ($0 < \tau \leq 120$) followed by two sharp spikes, one at 13:00PM ($\tau = 240$) and the other at 15:00PM ($\tau = 480$). The relaxation of intraday spread in the first hour can be expressed as follows

$$\overline{S}(\tau) \sim \tau^{-\beta},$$

where $\beta = \beta_{\text{SHSE}} = 0.20 \pm 0.002$ for the SHSE stocks and $\beta = \beta_{\text{SZSE}} = 0.19 \pm 0.002$ for the SZSE stocks. In order to test the relativity between $\tau$ and $S$ in the regression equations, $t$-test is used here. The $t$-statistic for SHSE is $|T| = 93.025 \gg 4.0277 = t_{0.99995}(118)$, while that for SZSE is $|T| = 83.636 \gg 4.0277 = t_{0.99995}(118)$. 

7
Fig. 5. Power-law relaxation of $\overline{S}(\tau)$ with respect to $\tau$ within the first hour of continuous double auction from 9:30AM to 10:30AM for SHSE stocks (a) and SZSE stocks (b). The dashed lines are the best power-law fits in the scaling range $\tau \in [1, 120]$. The unit of $\tau$ is 30 seconds.

4.2 Power-law decay of intraday spreads $\overline{S}_i(\tau)$

When the intraday spreads $\overline{S}_i(\tau)$ for individual stocks are considered, we find similar power-law relaxation in the first hour of the continuous double auction. Two typical examples (stock 600100 traded on the SHSE and 000031 traded on the SZSE) are illustrated in Fig. 6. The power-law behavior can be fitted to the following formula

$$\overline{S}_i(\tau) \sim \tau^{-\beta_i}.$$  \hspace{1cm} (9)

Least-squares regressions give $\beta_{600100} = 0.23 \pm 0.005$ and $\beta_{000031} = 0.23 \pm 0.006$. The scaling range used for fitting is $\tau \in [1, 80]$. The relaxation exponents of these two arbitrarily chosen stocks are not completely close to the market-averaged exponents. This calls for a detailed investigation of the distribution of the power-law relaxation exponents $\beta_i$.

Fig. 6. Power-law relaxation of $\overline{S}_i(\tau)$ with respect to $\tau$ within the first 40 minutes of continuous double auction from 9:30AM to 10:10AM for SHSE stock 600100 (a) and SZSE stock 000031 (b). The dashed lines are the best power-law fits in the scaling range $\tau \in [1, 80]$. 
Here we investigate in detail the relaxation exponent $\beta_i$ of intraday spread $S_i(\tau)$ for individual stocks traded on the SHSE and the SZSE. Figure 7 draws the histograms of the power-law relaxation exponent $\beta$ for the SHSE and the SZSE respectively. We find that $\beta_{\text{SHSE}} = 0.20 \pm 0.067$ and $\beta_{\text{SZSE}} = 0.19 \pm 0.069$. In addition, the skewness are $\nu_{\text{SHSE}} = -0.5330$ and $\nu_{\text{SZSE}} = -0.3309$, while the kurtosis are $\kappa_{\text{SHSE}} = 3.0187$ and $\kappa_{\text{SZSE}} = 2.7016$. The two distributions can be modeled roughly by normal distributions. Since the mean and variance of the sample are unbiased estimates for normal distribution, the null hypothesis $H_0$ can be expressed as follows

$$\begin{aligned}
\beta_{\text{SHSE}} &\sim \mathcal{N}(0.20, 0.0067) \\
\beta_{\text{SZSE}} &\sim \mathcal{N}(0.19, 0.0069)
\end{aligned}$$

where $\mathcal{N}(\mu, \sigma^2)$ is the normal distribution with mean $\mu$ and variance $\sigma^2$. We test the hypothesis by means of $\chi^2$ test. We find that $\chi^2_{\text{SHSE}} = 155 < 157 = \chi^2_{0.9999}(97)$, $\chi^2_{\text{SZSE}} = 95 \leq 96 = \chi^2_{0.5}(97)$. Speaking differently, the normality of power-law relaxation exponents $\beta$ for both SHSE and SZSE stocks can not be rejected.

![Histogram of relaxation exponent $\beta$ for all the stocks traded on the SHSE (a) and the SZSE (b). The dashed lines in both plots are the best fits to Gaussian distributions.](image)

**5 Summary**

We have studied the intraday patterns in the bid-ask spreads of 1364 Chinese A-share stocks using high-frequency data. The daily periodicity in the spread time series is confirmed by Lomb analysis. The intraday bid-ask spreads exhibit $L$-shaped pattern. The intraday spread of individual stocks relaxes as a power-law in the first 40 minutes of the continuous double auction from 9:30AM to 10:10AM. We have found that the averaged power-law decay exponents are $\beta_{\text{SHSE}} = 0.20 \pm 0.067$ and $\beta_{\text{SZSE}} = 0.19 \pm 0.069$. The chi-squared test shows that the relaxation exponent $\beta$ of individual stocks is normally distributed.
It is interesting to note that the value of $\beta$ enables us to classify the widening of the spread in the cooling period (from 9:25AM to 9:30AM) as an endogenous process. According to the network theory of peaks in complex systems [29], an endogenous peak decays as a power law $\sim \tau^{-1-2\theta}$, while an exogenous peak relaxes as $\sim \tau^{-1-\theta}$. We find that $\theta \approx 0.4$, which is in line with the endogenous exponents observed in other complex systems such as the dynamics of book sales and online download of articles [29][30][31][32].

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