Published in "Physica A: Statistical Mechanics
and its Applications 392(19): 4435–4449, 2013"
which should be cited to refer to this work.

Impact of monetary policy changes on the Chinese monetary and stock markets

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The impact of monetary policy changes on the monetary market and stock market in China is investigated in this study. The changes of two major monetary policies, the interest rate and required reserve ratio, are analyzed in a study period covering seven years on the interbank monetary market and Shanghai stock market. We find that the monetary market is related to the macro economy trend and we also find that the monetary change surprises both of lowering and raising bring significant impacts to the two markets and the two markets respond to the changes differently. The results suggest that the impact of fluctuations is much larger for raising policy changes than lowering changes in the monetary market on policy announcing and effective dates. This is consistent with the "sign effect", i.e. bad news brings a greater impact than good news. By studying the event window of each policy change, we also find that the "sign effect" still exists before and after each change in the monetary market. A relatively larger fluctuation is observed before the event date, which indicates that the monetary market might have a certain ability to predict a potential monetary change, while it is kept secret by the central bank before official announcement. In the stock market, we investigate how the returns and spreads of the Shanghai stock market index respond to the monetary changes. Evidences suggest the stock market is influenced but in a different way than the monetary market. The climbing of returns after the event dates for the lowering policy agrees with the theory that lowering changes can provide a monetary supply to boost the market and drive the stock returns higher but with a delay of 2 to 3 trading days on average. While in the bear market, the lowering policy brings larger volatility to the market on average than the raising ones. These empirical findings are useful for policymakers to understand how monetary policy changes impact the monetary and stock markets especially in an emerging market like China where the economy is booming and the policy changes impact the markets as surprises by the central bank without a pre-decided schedule. This is totally different from previous studies on FED, which follows pre-decided schedules for monetary policy changes.

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1. Introduction

Monetary policy changes made by the central bank of each country can bring a great influence to the financial markets [1]. A central bank can lower or raise benchmark rates to adjust the economy, which is similar to the interest rate. Several researchers [2–7] study how the Federal Reserve Board(FED), the central bank of the United States influences the markets both from the traditional finance research perspective [2,8–11] and statistical physics [12,13]. Some studies report stock markets respond differently to different policy actions and types [2,5]. For other countries and regions like South East Asia [14], the link between monetary policy and asset prices is also investigated. In study [15], the results suggest there is asymmetrical volatility before and after a Federal Open Market Committee (FOMC) meeting event in the Irish stock market. Similar research is conducted in the markets from Germany and the UK, where asset prices are negatively influenced by the UK monetary policy changes [16]. In the Euro Area, studies [17–20] focus on how the monetary policy changes made by the European Central Bank (ECB) can influence the markets. Expansionary monetary policy can lead to higher market liquidity in German, French and Italian markets [18], the ECB makes a clear impact on volatilities of the European index return [19]. The monetary policy changes are also studied from 13 countries in the Organization for Economic Co-operation and Development (OECD) [21] and Canada [22]. A wider collection of 16 countries are investigated in Ref. [23] and the authors find monetary policy changes influence the stock market returns on a monthly and quarterly basis. However, there is still a lack of study on how the market responds to the monetary changes in emerging markets like China, since the mechanisms of monetary policy changes adapted by other central banks might be different between developed countries and emerging markets like China. While some studies only focus on how the stock market responds [24], it is important to investigate how the monetary market responds to the monetary policy changes in China.

In this paper, we conduct research on the impact of the monetary policy changes made by the central People's Bank of China (PBC) to the monetary market and the stock market. Results of analysis suggest that the Shanghai Interbank Offered Rate (SHIBOR) monetary market and Shanghai stock market respond differently to the changes of interest rate (R) and required reserve ratio (RRR). In a bear market, lowering R or RRR can bring a larger fluctuation into the stock market and a smaller fluctuation into the monetary market. There is a significant "sign effect" [12,25] that raising RRR or R can bring larger fluctuations to the SHIBOR market, while raising policies will impact the monetary markets more. For the stock market, there is an approximately two-day-delay for lowering policies to take effect, to drive the stock market index higher, which also agrees with the fact that lowering policies can provide a stronger money supply into the market and boost the market. For the SHIBOR market, the average fluctuations reach peaks at 1 or 2 days before the policy changes announcement dates and effective dates. This indicates the SHIBOR market has a certain predictability for monetary change surprises which the PBC keeps secret and releases as surprises without any schedules. All the 34 RRR changes and 16 R changes between 2006-10-08 and 2012-05-11, covering1401 trading days are studied in this research.

This paper is organized into four sections as follows. In Section 2, the Chinese monetary policy tools of RRR and R, the Chinese interbank monetary market index SHIBOR and the Shanghai stock market are introduced. In Section 3, the research method and data collection results with analysis are presented. The conclusions, discussions, contributions, and limitations are provided in Section 4.

2. Chinese monetary policy, SHIBOR and Shanghai stock market

After nearly thirty years of miraculous economic development since the 1980s with a stunning annual Gross Domestic Product (GDP) growth of over 8%, China has built an expanding economy that has overtaken Japan as the second-biggest only after the US and is expected to replace the US as the world's largest economy in the near future. While enjoying a huge economic boom, China is also suffering from serious problems of rising salary, energy and raw material costs along with the huge pressure to raise the Renminbi Yuan (RMB) currency exchange rate which erodes China's exports, a rapidly climbing Consumer Price Index (CPI), and speculating demand for property. It is a great challenge and also a top priority for the Chinese government to maintain an economic growth rate at the same high level while taming persistent inflation. China sticks to a so-called appropriate loose monetary policy in order to achieve healthy economic development.

The People's Bank of China (PBC), the central bank of China, plays a similar role of monetary policy maker as the FED reserve in the US to maintain the stability of the value of the currency and thereby promote economic growth. In PBC's monetary policy toolbox, major instruments are reserve requirement ratio (RRR), central bank base interest rate (R), rediscounting, central bank lending, and open market operation [26]. Among them, RRR and R have a significant influence over the market and draw great attention from the public. What makes it more interesting is that the PBC's monetary committee announces all of the changes of both rates as sudden surprises without schedules. This is quite different from the way FED reserve makes rate change announcements, which will mostly follow a pre-determined schedule of Federal Open Market

Committee (FOMC) meetings. Once PBC announces the changes of RRR or R, the money market and stock market will be impacted and be forced to respond to the new policy by absorbing the information in the markets. Since the changes come as surprises, the market is not likely to predict exactly the announcing dates but the market activities will reflect the market expectation of a coming monetary policy change.

RRR is a PBC regulation which demands the minimum reserves ratio for each commercial bank deposit made with PBC to its total customer deposits. Because of the exponential effect, which means loaned money can be re-loaned to generate more money in the market, PBC uses RRR as a major inflation-fighting monetary policy tool by normally raising the RRR to lower the exponential effect in order to reduce the money supply to the market and maintain the money purchasing power. RRR changes are announced by PBC suddenly but the targeted ratio is set to be effective with a time lag of more than a week normally. Due to the 2008 financial crisis, the PBC adapted a new RRR policy demanding a different RRR for large financial institutes and medium–small financial institutes respectively. While the large financial institutes like commercial banks and institutional investors are the most influential major players in the market, we will focus on the RRR for large financial institutes in this research.

PBC's interest rate (R) is also another tool to battle against the high inflation and bubbles in property and other markets. The benchmark one-year (1Y) deposit rate and lending rate are raised as surprises in order to lower the market investments and also ease the pressure of the appreciation of RMB by locking more money in banks and raising the cost of money lending. PBC normally sets the effective day on the same announcing day or the following day. The direct result of a climbing R will push commercial banks to raise the interbank interest rates, which leads to a higher lending cost between financial institutions and lower speculation in the market. For each R change, PBC sets two benchmark one-year bank rates to lend and deposit rates respectively. Generally speaking, the lending rate is higher than the deposit rate, but these two rates share similar movements. Since we investigate the ask prices between banks which are more closely related with the lending rate, so in this study we choose to use the lending interest rate.

The Shanghai Interbank Offered Rate (SHIBOR) is the Chinese version of the London Interbank Offered Rate (LIBOR) and Federal Funds Interest Rates. By arithmetically averaging all the interbank RMB bid–ask rates offered by a group of 16 quotation banks, which are major active players in the RMB money market with high credit ratings, the National Interbank Funding Center (NIFC) in Shanghai announces the daily SHIBOR rate of eight maturities from overnight, to one week, to one year. Among them the overnight is the most used daily rate by institutes in pricing financial products [27]. After the introduction of SHIBOR in 2006, it has become the de facto interest rate market benchmark. Since SHIBOR is a result of open market trading games between commercial banks reflecting the money supply–demand situation in the market, SHIBOR has become a market index to measure the market liquidity and the market expectation to a potential monetary policy change. The two independently operating stock markets, Shanghai stock market (SHSM) and Shenzhen stock market (SZSM), together compose the Chinese stock market (CSM). The stock market is very sensitive to any monetary policy changes and the market volatility is also a result of investor expectation. In this study, we use the daily index data of the Shanghai stock market where major industrial companies and financial companies are listed and focus on the dynamics of SHIBOR and SHSM responding to the monetary policy changes of RRR and R.

3. Data and results

In this part, we analyze the history of PBC's changes of both RRR and R, all the SHIBOR daily prices and quotes, and the daily index of SHSM for the 6-year-period from 2006/10/08 to 2012/05/11. The change dates are collected from the official website of the PBC and the SHIBOR data are collected from the SHIBOR data services [27]. Since SHIBOR was introduced in 2006, we only use the RRR and R SHIBOR data, which are available from 2006 to 2012. To investigate the impact on the stock market, we use the Shanghai stock market index data during the same study period.

3.1. RRR and R

After the first time RRR was introduced in 1984, there have been in total 46 changes of RRR until 2012. While the SHIBOR was first introduced in 2006, we only consider the RRR changes after the introduction of SHIBOR. During the study period between 2006/10/8 and 2012/5/11, there have been 34 RRR changes. As shown in Fig. 1, the RRR is almost constantly climbing from 6% to a stunning high of 21% and normally with an increment of 0.5% for each time, except the period of the 2008–2009 global financial crisis, during which RRR experienced a temporarily drop by 4% to counter the crisis. Before 2006, there were only 7 changes over 20 years, but after 2006, the PBC more and more frequently raised the RRR to control the economy, 33 times in total, nearly 6 times per year. In the first five months of 2011, PBC even raised RRR 5 times monthly. In 2012, there are 2 drops of RRR when the market needed stimulation and more money supply.

Normally, RRR changes are announced by PBC as surprises when markets are closed during evenings or during holidays in order to minimize the impacts to markets. The dates on which RRR changes are announced are called RRR announcing dates or D^a_{rrr} on which a new RRR and the effective date for the new RRR comes into effect are announced by the PBC. The effective dates on which the new RRR becomes effective, D^e_{rrr}, are normally about one week after the announcing dates, D^a_{rrr}. The value of the RRR is denoted as rrr.

The interest rate R also has a great influence and impact on the markets. Before 2006, PBC did not frequently change the R and maintained the R at a low level of 2.25%, but after 2006, PBC began to frequently change the R from 2.25% to 3.25%

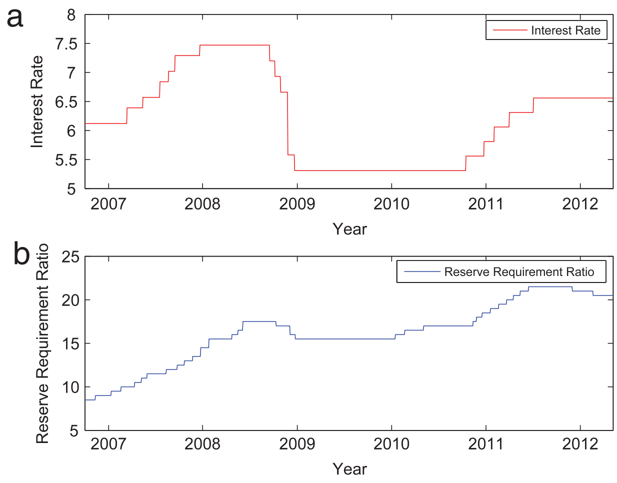


Fig. 1. (Color online) During our study period between 2006/10/8 and 2012/5/11, we plot the daily interest rate R and reserve requirement ratio RRR. In 1401 trading days, PBC changed R and RRR 16 times and 34 times respectively. Among them there are 5 instances of R lowering and 6 instances of RRR lowering, and most of them happened during the period of 2008, whereas the global financial crisis accrued and PBC lowered the two rates to provide more money supply into the market, hoping to stimulate the economy. The two curves correlate with each other suggesting that PBC will normally raise or lower R and RRR jointly to control the money supply and economic growth.

with each change normally of 0.25%. There are 16 changes of the R over the period from 2006 to 2011. As shown in Fig. 1, R has a similar shaped curve as RRR, and the R experienced a fast descending phase in the year of 2008, which is the same period as the global financial crisis. During that period, by lowering the R 5 times from 4.14% straight to 2.25%, PBC took a loose monetary policy to stimulate the economy in order to counter the negative influence of the crisis. We denote the value of the R as r. Since the first R change on 1990/4/15, there are 32 R changes until 2012. By considering the data availability of SHIBOR data, we focus on the 16 instances of R changes during our study period from 2006/10/8 to 2012/5/11.

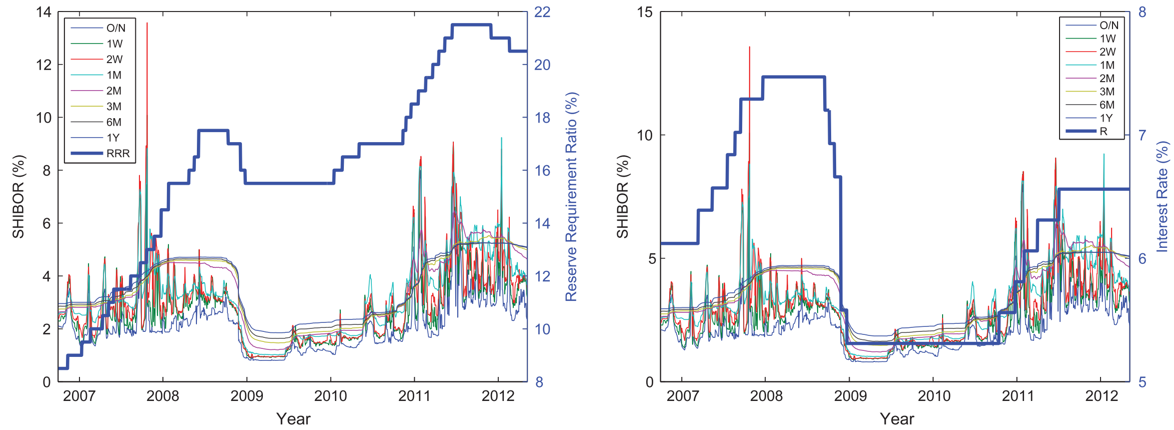
Like the sudden announcing of RRR change, PBC also announces a new R as a surprise without any pre-decided schedules. The announcements are released by PBC after the close of markets or during holidays to avoid a huge impact on the market. The announcing date of R changes, denoted as D_r^a, normally leads the effective date by one day, denoted as D_r^e, on which the new R comes into effect.

3.2. *SHIBOR and SHSM*

SHIBOR was introduced to the market in 2006 by NIFC. All prices of the eight SHIBOR interest rates with different maturities are calculated, announced and published by NIFC in Shanghai on a daily basis. The maturities of the eight SHIBOR interest rates are overnight (O/N), one week (1W), two weeks (2W), one month (1M), two months (2M), three months (3M), six months (6M), and one year (1Y). For each maturity, SHIBOR publishes two interest rates for ask and bid. The ask interest rate is the interest rate asked by a lending bank from other borrowing banks and the bid interest rate is the interest rate accepted by a borrowing bank from other lending banks. Normally an ask interest rate is higher than a bid interest rate for the same maturity. Since the rates for ask and bid are symmetric, without loss of generality, in this research the ask rate is the focus, which is highly related to the PCB's lending interest rate, R. Two SHIBOR datasets are analyzed in this study. One is the daily bid–ask quote for all 8 products from a panel of 16 major active Chinese commercial banks. The other is the final daily bid–ask price arithmetically averaged by the NIFC with exclusion of the two highest and two lowest prices. We use $a_i^s(t)$ and $b_i^s(t)$ to denote the daily ask and bid rates for SHIBOR (s) of product i on date t respectively. For the daily ask and bid rates of product i of bank j on date t, they are denoted as $a_i^j(t)$ and $b_i^j(t)$.

SHIBOR plays the benchmark role for the Chinese monetary and financial markets where many financial instruments and products are taken from SHIBOR as the base rate. As a result of games among banks of the monetary market, SHIBOR is influenced by the monetary policy and is very sensitive to any changes of the RRR and R, which are the major monetary instruments applied by the PBC to adjust the money supply and liquidity of the monetary market and through it to influence the economy. How the monetary policy changes of RRR and R will impact the SHIBOR is what we are interested in exploring in this study.

The daily data of SHIBOR-RRR and SHIBOR-R in our study period between 2006 and 2012 are plotted in Fig. 2(a) and (b) respectively. All eight daily SHIBOR rates are plotted which demonstrate a similar shape between RRR and R. Also, we can observe that the fluctuations of SHIBOR rates are related with the changes of RRR and R, i.e. during changing periods of RRR and R, SHIBOR rates fluctuate significantly, while during non-changing periods, SHIBOR rates are relatively smooth. We also use the daily index of the Shanghai stock market (SHSM) to study how the stock market responds to the monetary policy changes. The SHSM index was launched in 1991 with a base value of 100 and constituents for the index are all listed stocks on the Shanghai stock market. The SHSM index now represents the fastest growing stock market in the whole world with



(a) SHIBOR and RRR.

(b) SHIBOR and IR.

Fig. 2. (Color online) (a) All of the eight maturities of SHIBOR prices including o/n, 1w, 2w, 1m, 2m, 3m, 6m and 1y are plotted with the RRR into the same study period between 2006/10/8 and 2012/5/11. In our study period, the RRR experienced 34 changes, including 28 instances of raising and 6 instances of lowering. The first lowering period accrued in 2008 during the global financial crisis, PBC lowered the RRR to fight the crisis and stimulate the economy and the second lowering period happened in 2012 to fight against the inflation when the RRR reached the historic stunning highest level of 21.50% after years of raising. From this figure, we see that during the frequent changing periods of RRR, SHIBOR prices exhibit larger fluctuations. (b) All of the eight maturities of SHIBOR prices including o/n, 1w, 2w, 1m, 2m, 3m, 6m and 1y are plotted with the interest rate R into the same study period between 2006/10/8 and 2012/5/11. In our study period, the R experienced 16 changes, among them 11 instances of raising and 5 of lowering. The lowering period was also within the 2008 global financial crisis during which the PBC lowered the R to put more liquidity into the market in order to boost the market. As shown, during the frequent changing periods of R, SHIBOR prices exhibit larger fluctuations.

listed companies covering all major sectors of the economy. The index used in this study is the composite index, which is over 2100 points when this study is conducted with daily trading of over 59 billion RMB, nearly 9.3 billion dollars.

In order to understand the SHIBOR market, correlation analysis was conducted on the SHIBOR market by using the panel bank level data. There has been increasing interest in using correlation analysis on various financial markets as the correlation study is the start point for further exploring the structures of different markets [28].

The correlation matrix for a financial market indicates the movement behaviors among the financial assets or prices. The matrix can be used to extract useful information, especially the properties of dependency and collective behavior of each pair. Most studies calculate the correlation matrix by using the time series data over the whole study period. This approach is simple to gain the long-term relations among the financial time series but fails to reveal the dynamic interactions changing and evolving over the study period. We use a sliding window along the period to gain insights into how banks interact with each other in different times. First we study the eigenvalues of the correlation matrix of the 13 prices from October 8, 2006 to August 31, 2012. By using the daily overnight ask prices of 13 banks, there are 13 time series. In order to study the evolutionary properties of the correlation matrix, we construct a sliding window with a size of $N \times L$, where the width $N = 13$ is the number of banks and the length L is the length of the time series to calculate the correlation matrix C^t_{ij} at Time $= t$ which is a $N \times N$ matrix with elements defined as the widely used Pearson correlation coefficient,

$$\rho^t_{ij} = \frac{\langle p_i p_j \rangle - \langle p_i \rangle \langle p_j \rangle}{\sigma_i \sigma_j}, \tag{1}$$

indicating the correlation coefficient between bank i and bank j on date Time $= t$, where $\rho^t_{ij} = 1$ means the two banks are well correlated, $\rho^t_{ij} = -1$ means the two banks are completely anti-correlated and $\rho^t_{ij} = 0$ means the two banks are completely uncorrelated. In this study, we choose a length of $L = 30$ representing 30 trading days, which is the same length as the authors chose in the study [29]. The average correlation,

$$\langle C^t_{ij} \rangle = \langle \rho^t_{ij} \rangle_{i \neq j} \tag{2}$$

is calculated over the non-diagonal elements [29,30] to study the collective behavior of the market. By using the sliding window over the whole study period, we calculate the eigenvalues $\lambda_1, \lambda_2, \ldots, \lambda_N$ of C^t_{ij} for each time t, and label the ith largest eigenvalue as λ_i.

The eigenvalue distribution of a correlation matrix of financial time series is useful to extract the embedded information, which is normally covered by noise among the time series. The largest eigenvalue λ_1 is also believed to be an index representing the behavior of the whole market, here in our case the 13 banks. It is also observed in previous literatures [29,31–33] that the largest eigenvalue λ_1 is associated with the so-called "market mode", when all participants share a similar sentiment or expectation of the market, making the financial assets behave in a collective way, fluctuating up or down synchronically. In our case, the 13 banks will quote prices well correlatively in a market mode. While the remaining smaller eigenvalues are quite sensitive to the market noises, they still contain certain information on the market. The average

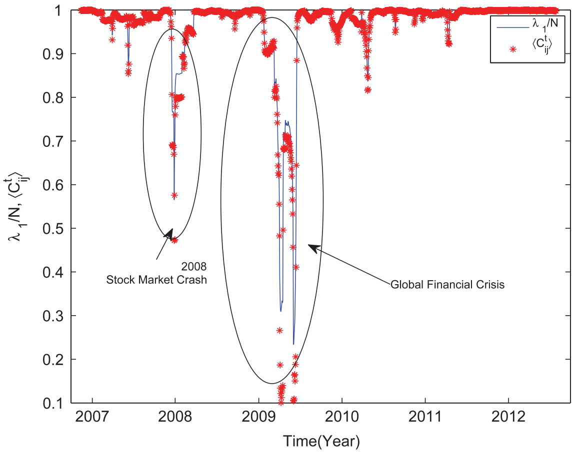


Fig. 3. (Color online) The largest eigenvalue λ_1/N and the average correlation $\langle C_{ij}^t \rangle$ of the daily correlation matrix C fits every well, i.e. $\lambda_1/N \sim \langle C_{ij}^t \rangle$ showing that λ_1/N is a perfect estimator of the average correlation of the market matrix. This also indicates that the banks share a similar market mode. The majority of time the banks share similar and close market sentiment and expectation, in other words, the banks behave in a synchronized way, lowering or raising prices together. But there are some exceptional periods as shown in the plot, especially in the huge drop period of λ_1 around 2008 and 2009, which are exactly the periods of the historical stock market crash in 2008 and the great global financial crisis in 2009 respectively. The simultaneous drops of λ_1/N and $\langle C_{ij}^t \rangle$ indicate that the banks behave differently in the crisis, bringing much noise. At the same time the market mode is weakened, indicating that the banks have different expectations and views about the market, losing the common collective behavior which correlates well the quotation prices in the "non-crisis" periods.

correlations of pairs in the correlation matrix can be estimated from the largest eigenvalue as,

$$\lambda_1/N \sim \langle C_{ij}^t \rangle, \tag{3}$$

capturing the collective behavior of all participants [32]. As plotted in Fig. 3, the curves of λ_1/N and $\langle C_{ij}^t \rangle$ fit very well for the majority of time with slight differences in the periods of large dropping of the largest eigenvalue λ_1 and the average correlation of banks $\langle C_{ij}^t \rangle$. They are exactly the periods of the 2008 Chinese stock market crash and the global financial crisis in 2009. This indicates that for the majority of time, except for the two major dropping periods, the prices of all banks move in a market mode, raising or lowering the prices in the same direction. $\lambda_1/N \approx \langle C_{ij}^t \rangle \approx 1$ means in the market mode the banks' behaviors are well correlated, but in the major dropping periods. To study the behavior in different market periods, we calculate the average of both $\langle C_{ij}^t \rangle$ and λ_1/N over four periods, the $\langle\langle C_{ij}^t \rangle\rangle$ is 0.8530 and 0.6911 for the 2008 stock market crash and 2009 global financial crisis respectively, while $\langle\langle C_{ij}^t \rangle\rangle = 0.9896$ for the remaining normal "non-crisis" periods. Similarly, the $\langle \lambda_1/N \rangle$ is 0.8857, 0.7391 and 0.9897 for the 2008 stock market crash, the 2009 global financial crisis and the remaining normal "non-crisis" periods respectively. We find that in the two major dropping periods of 2008 and 2009, the market mode disappears when both of the λ_1 and $\langle C_{ij}^t \rangle$ drop greatly and the banks are relatively less correlated compared to the normal "non-crisis" periods. It is very interesting since it is reported that the market will be in a strong co-movement mode, i.e. market mode, when the market suffers a crisis or a bad market period during which all participants' behaviors are similar, resulting in a high correlation $\langle C_{ij}^t \rangle \approx 1$, like in the Korean stock market when the average correlation $\langle C_{ij}^t \rangle$ reached the highest peak in the stock market crash caused by the 1998 Asian currency crisis [34]. In another study [29], by analyzing correlation properties of the financial markets around the world in a time of crisis, the authors find that the market tends to behave similarly with high correlation and volatility. However, in this SHIBOR market, all banks' behaviors are less correlated with much a smaller correlation $\langle C_{ij}^t \rangle$. This can be explained due to the fact that crisis or bad market environment, all banks have very different views and expectations of the market and the quotes diversify among the panel banks making the market. This is evidence that the panel banks make quotes independently, otherwise if there is secret information shared among the panel banks, they will be correlated well even in a crisis or bad market periods by quoting similarly, which is not the case as shown in our results. The initial correlation analysis of the SHIBOR market focusing on the eigenvalue distribution reveals that SHIBOR quoting prices are related with the macro economy markets, which indicates the importance of the SHIBOR market. Further analysis of the statistical properties of the SHIBOR market is needed to understand the dynamics of the SHIBOR prices.

3.3. Results

3.3.1. Monetary changes and SHIBOR market

In this section we investigate the behavior of SHIBOR rates reacting to the monetary changes of RRR and R. As mentioned above, we only focus on overnight ask rate, $i = 1$, which is more sensitive to the monetary policy changes. With the 16 daily ask quotes from the panel banks, for the date $T = t$, the factors below are analyzed, the average $\langle a_1(t) \rangle$, deviation

Table 1
For different events Dates sets, we calculate the averages $\langle s \rangle$, $\langle\langle a_1(t)\rangle\rangle$, $\langle\sigma\rangle$, $\langle \max\rangle$, $\langle \min\rangle$ and $\langle \text{spread}\rangle$, all are averaged on the number of the dates. The table rows are sorted in descending order of the $\langle\sigma\rangle$. For example, when the Dates set is $D^{a,e}_{rrr\pm,r\pm}$, this indicates the total of 93 dates which belong to $D^{a,e}_{rrr+} \cup D^{a,e}_{rrr-} \cup D^{a,e}_{r+} \cup D^{a,e}_{r-}$, where a, e indicates both announcing dates and effective dates are included and $rrr\pm$ indicates both the raising and lowering dates for RRR are included. $\langle\cdot\rangle$ is a result of the average over all 93 dates. In this table, there are 28 different Dates sets including *ALL* for all the dates during our study period. As the table results indicate, dates of D^a_{r+} have the highest $\langle\sigma\rangle = 0.0619$ and also the highest $\langle\text{spread}\rangle = 0.2533$ while for the whole 1401 trading dates in our study period, denoted as *ALL*, the $\langle\sigma\rangle$ is only ranked in a very low place with $\langle\sigma\rangle = 0.0257$ and $\langle\text{spread}\rangle = 0.0992$. The orders of $\langle\sigma\rangle$ and $\langle\text{spread}\rangle$ are almost identical, which means that the $\langle\text{spread}\rangle$ fluctuates with the $\langle\sigma\rangle$, but this effect is not found for the remaining variables. Interestingly, the dates on which RRR or R is raised $+$ dominate the upper parts followed by the dates of both raising and lowering dates $\pm$, while the dates of the lowering of RRR or R have the minimum σ and minimum spread. This means that when the PBC raises RRR or R, the SHIBOR market experiences relatively larger fluctuations both on the a announcing dates and(or) e effective dates from D^a_{r+} to $D^a_{rrr+,r+}$. However, the SHIBOR market shows relatively smaller fluctuations when the PBC lowers the RRR or R on dates from D^a_{rrr-} to D^e_{r-}.

Dates	$\langle s\rangle$	$\langle\langle a_1(t)\rangle\rangle$	$\langle\sigma\rangle$	$\langle\max\rangle$	$\langle\min\rangle$	$\langle\text{spread}\rangle$
D^a_{r+}	2.7067	2.7105	0.0664	2.8635	2.5926	0.2709
$D^{a,e}_{r+}$	2.7020	2.7056	0.0626	2.8332	2.6080	0.2252
D^e_{rrr+}	2.6062	2.6041	0.0606	2.7120	2.4630	0.2490
$D^e_{rrr+,r+}$	2.6180	2.6173	0.0590	2.7208	2.4946	0.2262
$D^{a,e}_{rrr+,r+}$	2.4122	2.4131	0.0573	2.5329	2.3082	0.2247
D^e_{r+}	2.6482	2.6510	0.0551	2.7435	2.5753	0.1681
$D^{a,e}_{rrr+}$	2.2913	2.2912	0.0545	2.4061	2.1847	0.2214
$D^e_{rrr\pm}$	2.5884	2.5866	0.0529	2.6821	2.4660	0.2161
$D^a_{rrr+,r+}$	2.1317	2.1341	0.0522	2.2621	2.0521	0.2100
$D^{a,e}_{rrr\pm,r\pm}$	2.4206	2.4214	0.0506	2.5285	2.3300	0.1984
$D^{a,e}_{r\pm}$	2.5008	2.5032	0.0494	2.6021	2.4245	0.1775
$D^{a,e}_{rrr\pm}$	2.3528	2.3529	0.0493	2.4591	2.2589	0.2002
$D^e_{rrr\pm,r\pm}$	2.5459	2.5453	0.0491	2.6320	2.4446	0.1874
$D^a_{r\pm}$	2.5372	2.5394	0.0488	2.6488	2.4518	0.1970
D^a_{rrr+}	1.9719	1.9737	0.0471	2.0925	1.9044	0.1881
$D^a_{rrr\pm,r\pm}$	2.1923	2.1945	0.0463	2.3090	2.1223	0.1867
$D^a_{rrr\pm}$	2.1117	2.1136	0.0449	2.2282	2.0480	0.1801
$D^e_{r\pm}$	2.4557	2.4574	0.0410	2.5255	2.3993	0.1262
D^a_{rrr-}	2.7640	2.7668	0.0344	2.8614	2.7183	0.1430
$D^a_{rrr-,r-}$	2.6986	2.7002	0.0262	2.7687	2.6622	0.1065
$D^{a,e}_{rrr\pm}$	2.6346	2.6359	0.0257	2.7020	2.5992	0.1029
ALL	2.1574	2.1573	0.0257	2.2075	2.1084	0.0992
$D^{a,e}_{rrr-,r-}$	2.4575	2.4581	0.0211	2.5091	2.4265	0.0826
D^e_{rrr-}	2.5051	2.5049	0.0171	2.5427	2.4800	0.0627
$D^e_{rrr-,r-}$	2.2903	2.2897	0.0139	2.3169	2.2673	0.0497
D^a_{r-}	2.1642	2.1630	0.0101	2.1764	2.1420	0.0344
$D^{a,e}_{r-}$	1.8972	1.8959	0.0101	1.9089	1.8743	0.0346
D^e_{r-}	2.0324	2.0314	0.0100	2.0460	2.0120	0.0340

$\sigma(a_1(t))$, max $\max(a_1(t))$, min $\min(a_1(t))$ and spread $\text{spread}(a_1(t))$ between the max and min for each day t, as defined in Eqs. (4)–(6), where $j = 1, \ldots, 16$ stand for the 16 panel banks.

$$\langle a_1(t)\rangle = \frac{1}{16}\sum_{j=1}^{16} a_1^j(t) \tag{4}$$

$$\sigma(a_1(t)) = \left\langle (a_1^j(t) - \langle a_1(t)\rangle)^2 \right\rangle^{1/2} \tag{5}$$

$$\text{spread} = \max(a_1^j(t)) - \min(a_1^j(t)). \tag{6}$$

The SHIBOR fluctuations on event dates are analyzed. The SHIBOR prices are quotes from the 16 panel banks and all of them are major players in the monetary market and their quotes are very sensitive to the PBC's monetary policy changes of RRR and R.

The averaged deviation for all the date sets D are provided in Table 1 as

$$\langle\sigma\rangle = \frac{\sum_{t\in D}\sigma(t)}{|D|}, \tag{7}$$

where $|D|$ is the number of dates for all the possible date sets listed in the first column of Table 1. Similarly, we calculate the averaged spread as $\langle\text{spread}\rangle$. The fluctuations are results of the expectations of the 16 banks. When the market has a higher expectation of a monetary change in the future, the 16 banks might have different levels of expectations and this might mean higher fluctuations are likely to appear during the preceding days for a change of RRR or R. As we shall see in Table 1, on all event dates $D^{a,e}_{rrr\pm,r\pm}$, the $\langle\sigma\rangle = 0.0501$ and $\langle\text{spread}\rangle = 0.1963$ are almost twice the $\langle\sigma\rangle = 0.0257$ and $\langle\text{spread}\rangle = 0.0992$ for all the 1401 trading dates in our study period, which is denoted as *ALL*. Since we have times of raising as well as lowering

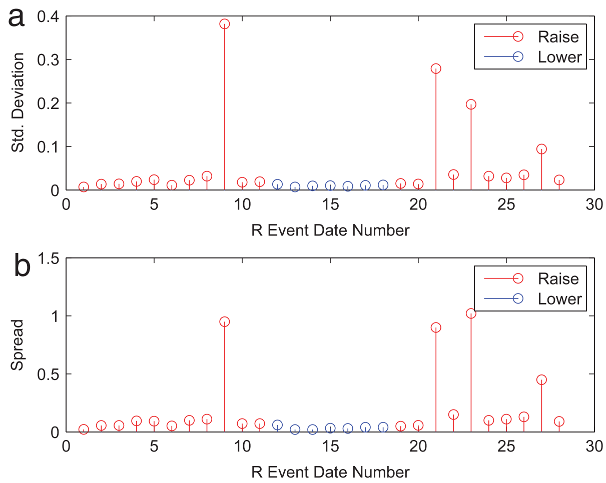


Fig. 4. (Color online) The $\langle\sigma\rangle$ and $\langle\text{spread}\rangle$ for all R event dates are plotted in (a) and (b) respectively through the whole study period between 2006/10/8 and 2012/5/11. There are in total 28 dates for the date set $D^{a,e}_{r\pm}$ which are composed of 21 dates (in red) of raising r in $D^{a,e}_{r+}$ and 7 dates (in blue) of lowering r in $D^{a,e}_{r-}$. The 7 dates of $D^{a,e}_{r-}$ range between 2008/09/16 and 2008/12/23 during which the PBC lowered the interest rate constantly 5 times by -0.27% each time to eliminate the liquidity brought by the lowering changes of foreign banks during the serious 2008 global financial crisis and also to stimulate investments and the economy as well as to maintain the confidence of markets by strengthening the money supply.

of RRR and R, it is interesting to find out that the SHIBOR market behaviors are dramatically different between raising times and lowering times of RRR and R. As shown in this table, which is sorted in descending order of the $\langle\sigma\rangle$, dates where RRR and(or) R are raised $(+)$ have the highest $\langle\sigma\rangle$ and $\langle\text{spread}\rangle$ and on the contrary, dates where RRR and(or) R are lowered $(-)$ have the lowest $\langle\sigma\rangle$ and $\langle\text{spread}\rangle$. The dates combining all raising and lowering dates are in the middle of the table. In other words, the SHIBOR market also reacts differently to the expectation for a pending monetary policy change. SHIBOR normally shows a larger fluctuation on the raising announcing dates and effective dates while showing a relatively smaller fluctuation on the lowering dates. One reason for this is that for a raising of RRR through which the PBC demands commercial banks to make more reserved money is definitely negative news for banks and the monetary market, with less liquidity and less available money for the market, all banking systems and the economic system will experience a tightened situation and market. Normally, a 50 basis point, i.e. 0.5% is going to absorb about 300 billion RMB or about 45 billion dollars. RRR is a very effective monetary tool used by the PBC in order to control the money supply in the Chinese monetary market. The raising of the benchmark interest rate R by the PBC is also a negative market signal for the market because the raising of R will attract and lock more money from the market back into the bank accounts and make the borrowing from commercial banks more costly. This makes it a useful tool to tighten the money supply and discourage investments and spending. It is also negative news for the monetary market when this is used to tackle the raising pressure of prices when the market is bullish and in great need of money supply for greater investment. On the contrary, a lowering RRR or R can bring more liquidity to the money supply, which provides more available and cheaper money to the market and eventually encourages more spending as well as stimulating aggressive investment in the economy. In other words, this lowering of RRR or R is a positive monetary policy change to the market. From the different levels of fluctuations for the negative and positive changes brought about by the raising or lowering RRR and R, this is very consistent with the effect that negative bad expectations normally bring a larger impact to the market than the positive good expectations. This result from the Chinese SHIBOR market agrees with the findings in the American market reacting to the FOMC news in studies in Refs. [11,12,35], that positive surprises tend to bring much higher volatility to the market than negative surprises.

Then we study and plot the $\langle\sigma\rangle$ and $\langle\text{spread}\rangle$ for the date sets of $D^{a,e}_{r\pm}$, $D^{a,e}_{rrr\pm}$ and $D^{a,e}_{rrr\pm,r\pm}$ in Figs. 4–6 respectively. The dates of raising and lowering R and RRR, i.e. $D^{a,e}_{rrr+,r+}$ and lowering $D^{a,e}_{rrr-,r-}$, are colored in red and blue respectively. During the period of the great 2008 global financial crisis period, the PBC lowered R 5 times, and RRR 4 times (3 times for large financial institutions and 1 time for small ones), the fluctuations are relatively small. From the calculation we find that the $\langle\sigma\rangle = 0.0626$ and $\langle\text{spread}\rangle = 0.2252$ for raising dates of $D^{a,e}_{r+}$ are much high than $\langle\sigma\rangle = 0.0101$ and $\langle\text{spread}\rangle = 0.0346$ for lowering dates of $D^{a,e}_{r-}$, and the same, for $D^{a,e}_{rrr+}$, we have a larger fluctuation $\langle\sigma\rangle = 0.0545$ and $\langle\text{spread}\rangle = 0.2214$, for $D^{a,e}_{rrr-}$, we have a smaller fluctuation $\langle\sigma\rangle = 0.0257$ and $\langle\text{spread}\rangle = 0.1029$, and for $D^{a,e}_{rrr+,r+}$, we have a larger fluctuation $\langle\sigma\rangle = 0.0573$ and $\langle\text{spread}\rangle = 0.2247$, for $D^{a,e}_{rrr-,r-}$, we have a smaller fluctuation $\langle\sigma\rangle = 0.0211$ and $\langle\text{spread}\rangle = 0.0826$. On one hand, this can be explained due to the fact that a negative $(-)$ adjustment of interest rate is good news for the monetary market, so the market shows smaller fluctuations, while positive $(+)$ adjustment is bad news which leads to smaller fluctuations on lowering dates and larger fluctuations on raising dates. On the other hand, the PBC's policy in the 2008 global financial crisis is very clear and the signals of the central government and PBC to fight against the crisis and to stimulate the economy were widely and publicly announced from time to time during that period. These kinds of signals of

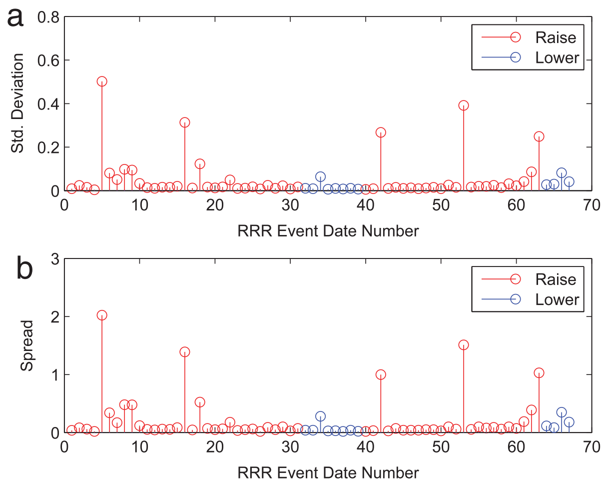


Fig. 5. (Color online) The $\langle\sigma\rangle$ and $\langle\text{spread}\rangle$ for all RRR event dates are plotted in (a) and (b) respectively through the whole study period between 2006/10/8 and 2012/5/11. There are in total 67 dates for the date set $D^{a,e}_{rrr\pm}$ which is composed of 55 dates (in red) of raising *rrr* in $D^{a,e}_{rrr+}$ and 12 dates (in blue) of lowering *rrr* in $D^{a,e}_{rrr-}$, for $D^{a,e}_{rrr+}$, we have larger fluctuations $\langle\sigma\rangle = 0.0545$ and $\langle\text{spread}\rangle = 0.2214$ and for $D^{a,e}_{rrr-}$, we have smaller fluctuations $\langle\sigma\rangle = 0.0257$ and $\langle\text{spread}\rangle = 0.1029$. There are two periods during which PBC lowered the RRR. The first period has 8 dates of $D^{a,e}_{rrr-}$ between 2008/09/15 and 2008/12/25, the same period as the 2008 global financial crisis when PBC also lowered the benchmark interest R. In the first period, PBC lowered RRR three times from 17.5% to 15.50% for larger financial institutions and once for smaller ones. In the second period, lowering happened twice at the end of our study period between 2011/11/30 and 2012/02/24, during which PBC lowered RRR 0.5% each time from 21.50% down to 20.50%.

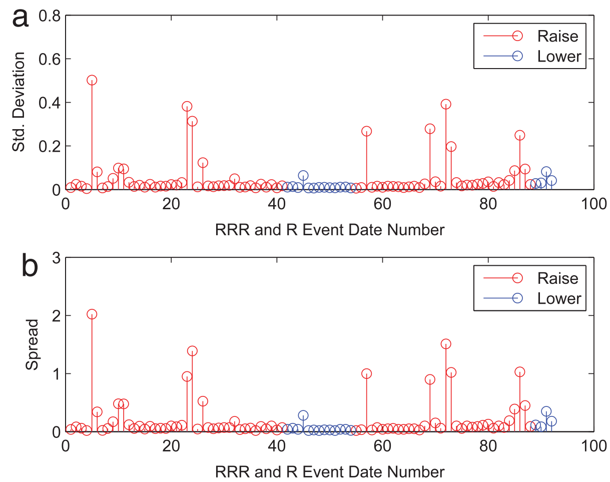


Fig. 6. (Color online) In this figure, $\langle\sigma\rangle$ and $\langle\text{spread}\rangle$ of all the raising (in red) and lowering (in blue) dates of R and RRR $D^{a,e}_{rrr\pm,r\pm}$ are plotted in (a) and (b) respectively. In our study period between 2006/10/8 and 2012/5/11, there are 92 dates in total and among them 75 dates are raising dates $D^{a,e}_{rrr+,r+}$ and 17 dates are lowering dates $D^{a,e}_{rrr-,r-}$. For the raising dates of $D^{a,e}_{rrr+,r+}$ the fluctuations where $\langle\sigma\rangle = 0.0573$, $\langle\text{spread}\rangle = 0.2247$ are much higher than the lowering dates of $D^{a,e}_{rrr-,r-}$ where $\langle\sigma\rangle = 0.0211$, $\langle\text{spread}\rangle = 0.0826$.

lowering the interest rate were very strong and clear, minimizing the differences of expectations among the market players and resulting in smaller fluctuations eventually.

The announcements of monetary policy changes, both of RRR and R made by PBC, are surprises and follow no pre-decided schedules, which are quite different to the scheduled FOMC. Based on the different expectation or speculations of possible changes of PBC made by the market players, the panel banks of SHIBOR will instantly change and respond to any information or signals they can observe from the market and these different levels of expectations will reflect in their different daily quotes prices and eventually bring fluctuations into the SHIBOR market. Until now, we have shown that on the event dates of most date sets, as shown in Table 1, most date sets have higher fluctuations than the date set *ALL* which has all the dates taken into account, where $\langle\sigma\rangle = 0.0257$ and $\langle\text{spread}\rangle = 0.0992$ and most lowering $(-)$ date sets from $D^{a,e}_{rrr-,r-}$ to D^{e}_{r-} are much lower than the date set of *ALL*, with only two exceptions of D^{a}_{rrr-} and $D^{a}_{rrr-,r-}$. The SHIBOR prices are calculated and published by the NIFC at 11:30 am on each business day, and this is hours earlier than the announcing time of changes of R or RRR made by PBC after the markets close on the exact same business day. So it is very interesting to find that we have significantly different, relatively higher (raising $+$) and smaller (lowering $-$) fluctuations on the date sets on which RRR and/or R are changed by PBC compared to the whole date set *ALL* in our study period. This indicates that the SHIBOR market has a certain predictive ability of a potential monetary change.

We have investigated how the SHIBOR market responds on event dates, the next step is to study how the SHIBOR changes before and after an event date, either for R or RRR, and also to study how it might behave differently between announcing dates (Time $= 0$) of $D^a_{rrr\pm,r\pm}$ and effective dates of $D^e_{rrr\pm,r\pm}$. To do this, we study a time window around the event date, we take a window size of 11 working days, in other words, we include the 5 days before and after the event date respectively. We calculate the averaged $\langle\sigma\rangle$, the fluctuations, for the ith day, which we obtain from the following equation,

$$\langle\sigma_i\rangle = \frac{\sum\limits_{t\in D,t=i} \sigma(t)}{|D|}, \tag{8}$$

where $i = -5 \cdots 5$, for each date of the date sets and plot the results of raising ones $(+)$ in red, lowering ones $(-)$ in green, and all raising–lowering ones $(\pm)$ in blue, as shown in Fig. 7(a)–(f). In Fig. 7(a), 16 times of the announcing of changes of R are averaged for raising ($+$, in red), lowering ($-$, in green) and both of raising and lowering ($\pm$, in blue) respectively. From this window study, we find that for all of the six sets, there are two significant interesting effects: (1) "Sign effect". The averaged fluctuations $\langle\sigma\rangle$ for raising R or(and) RRR (in red) are always higher the lowering R or(and) RRR (in green), while the fluctuation of raising and lowering dates (in blue) lies between the two of them. This is also consistent with the "sign effect" that negative changes of monetary policy (raising R or RRR) has a larger influence on the market than the positive changes (lowering R or RRR) [11,12,25,35]. (2) Leading fluctuation effect. We find that during the period of Time $= [-5, \dots, -1]$ before the announcing date Time $= 0$, the fluctuation has a significant climbing process leading to the period of Time $= [-5, \dots, 0]$ before the event dates where Time $= 0$ for the announcing dates D^a in (a), (c) and (e). The fluctuation reaches the highest peak on the dates one day before the announcing dates, Time $= -1$, for R changes in $D^a_{r\pm}$, on the announcing dates, Time $= 0$, for RRR changes in $D^a_{rrr\pm}$, and again on the dates one day before the announcing dates, Time $= -1$, for R–RRR changes in $D^a_{rrr\pm,r\pm}$. This effect shows that the SHIBOR market has a certain predictability regarding upcoming monetary policy changes, otherwise the fluctuation should not have an obvious climbing process and reach peaks before the announcing day. In other words, it might be possible that the commercial banks keep watching the market environment very carefully and any acts of the PBC sensing a PBC's upcoming monetary change might be due in order to reduce climbing inflation rates or to provide money supply into the market. It looks like the commercial banks have a certain collective intelligence that can predict an upcoming change. The PBC's sudden monetary changes are kept secret and would only be made public when they are released through the official announcements. We cannot tell the reason from the data, but the results show that the SHIBOR market is a good place to monitor the possible monetary changes, and the obtaining of a higher fluctuation before the announcing date is a result of the different sentiments of the commercial banks regarding the monetary markets. This stylized fact is a very interesting finding of the empirical study of the SHIBOR fluctuation behavior. It is also known that if there is a lead or lag between financial markets, there might be some opportunity to take advantage of these kinds of lead or lag time gaps to design a profitable trading strategy [36]. But it still needs comprehensive study and testing before any applications can be used.

3.3.2. Monetary changes and Shanghai stock market

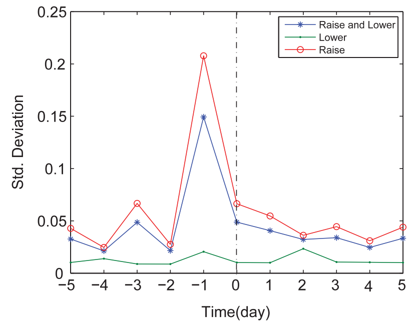
We have investigated the response of SHIBOR market to the monetary policy changes in the previous sections, now we focus on how the stock market might be influenced by the monetary changes of R and RRR. As we have mentioned before, most previous studies use stock market data, especially the S&P500 index prices data to study the impact of FED policy changes [5,6,8,11,37–39]. The S&P500 index and stock prices demonstrate a significant response to monetary policy changes, a price fall is observed after a rise of the FED funds rate [5] and, the empirical study in Ref. [6] reports a larger effect on the S&P500 index in the bear market. In a time widow of 30-min, a negative market response is found regarding the unexpected changes by FOMC [37]. Another study [11] focuses on the implied volatility and argues that a monetary policy change in expansive periods is more influential for both scheduled and unscheduled changes.

The situation in China is quite different from other countries. China is an emerging economy and the stock market is attracting more and more attention among the global financial markets, and the monetary policy changes are made without schedules, unlike the scheduled FOMC of FED. In this section, we use the daily index of the Shanghai stock market during the same study period between 2006-10-08 and 2012-05-11 to study how the stock market is impacted by the policy changes of PBC. We focus on the index return, defined as

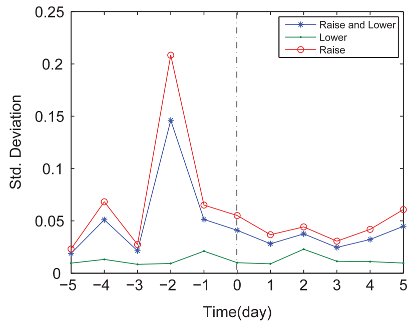
$$I_{\text{return}}(t) = \ln I(t) - \ln I(t-1), \tag{9}$$

which is logged daily return. We use an 11-day time window with event dates (Time $= 0$) in the middle and averaged the returns for the date sets of $D^a_{r\pm}$, $D^a_{r\pm}$, $D^a_{r\pm}$ and $D^a_{r\pm}$ to investigate how the stock market can be influenced by different changes. The averaged return of the ith day of date set D is defined as,

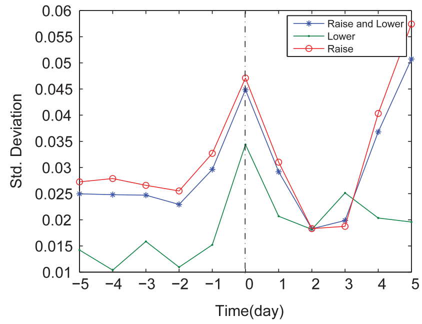
$$\langle I_{\text{return},i}(t)\rangle = \frac{\sum\limits_{t\in D,t=i} I_{\text{return}}(t)}{|D|}, \tag{10}$$



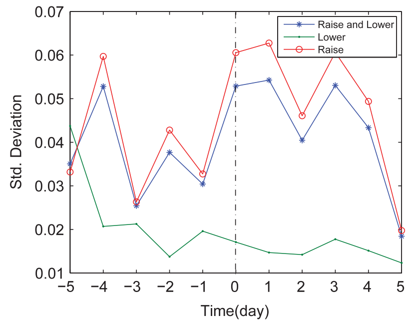
(a) $D^a_{r\pm}$.



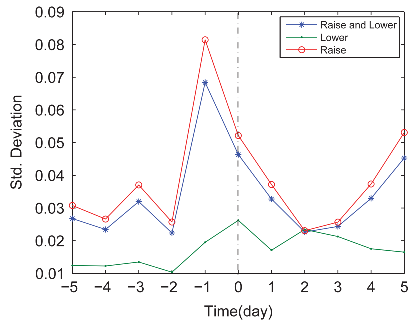
(b) $D^e_{r\pm}$.



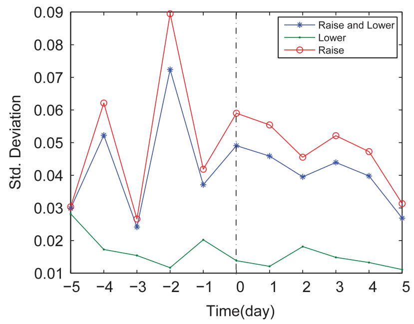
(c) $D^a_{rrr\pm}$.



(d) $D^e_{rrr\pm}$.



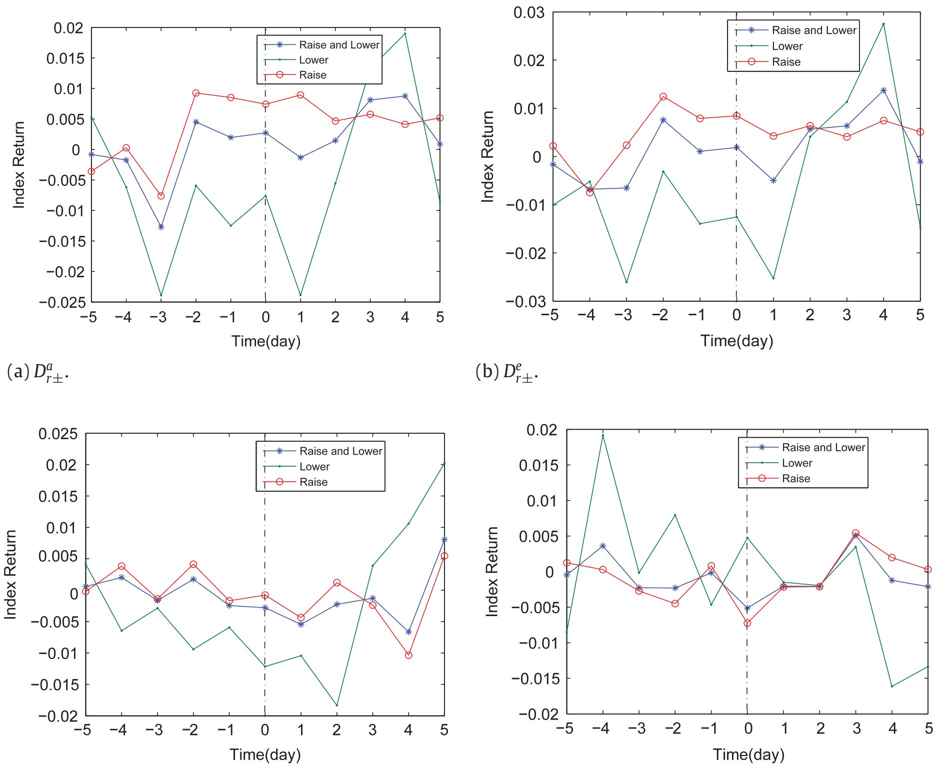
(e) $D^a_{rrr\pm,r\pm}$.



(f) $D^e_{rrr\pm,r\pm}$.

Fig. 7. (Color online) The averaged fluctuations $\langle\sigma\rangle$ of the SHIBOR market before and after the event dates are presented in this figure. By choosing 5 dates before and 5 dates after the event dates, we have a time window of 11 days Time $= [-5, \ldots, 5]$ which lies in the middle where Time $= 0$. To study how the markets fluctuate between the periods around the announcing dates and the effective dates, we use the 6 different date sets of $D^a_{r\pm}$, $D^e_{r\pm}$, $D^a_{rrr\pm}$, $D^e_{rrr\pm}$, $D^a_{rrr\pm,r\pm}$ and $D^e_{rrr\pm,r\pm}$ and plot the raising and lowering ($\pm$, in blue), lowering ($-$, in green) and raising ($+$, in red) in (a)–(f) respectively. From all 6 results, we find that during each window, the averaged fluctuation of raising events ($+$, in red) are much higher than those of lowering events ($-$, in green). This is also consistent with the similar results we find over the whole study period. The market has a much higher $\langle\sigma\rangle$ fluctuating on the left side of the time window, and also we find that on the event date where Time $= 0$, or Time $= -1 or - 2$, the $\langle\sigma\rangle$ shows the highest fluctuations over the whole time window. This very interesting and explicit observation shows that the SHIBOR market fluctuation levels changes before the events, and especially as shown in (a), (c) and (e), the SHIBOR market has a certain of predictive ability for the surprising announced changes of R or RRR on D^a.

where $i = -5 \ldots 5$. As plotted in Fig. 8(a)–(d), there are no significant changes of level of fluctuations of returns before and after the event dates for both lowering or raising R and RRR, also for the announcing dates or effective dates. But the returns of lowering R and RRR demonstrate a clear sharp jump and after Time ≥ 3, the lowering curve ($-$, in green) is above the raising curve ($+$, in red) as we can see in Fig. 8(a)–(c) except for the date set $D^a_{r\pm}$. This is a result of negative changes of R and RRR which can boost the market by providing more money supply and liquidity into the stock market and eventually drive the stock index higher [40], but clear drops in the index are not observed in the Shanghai market when the positive monetary policy change raises the R and RRR, which is not the same as S&P500 as reported in Ref. [5]. This jump happens with an averaged two days delay, which means the Shanghai stock market is much more influenced by the negative changes of R and RRR and the market takes nearly 2 days to adjust to the expected right situation, where negative changes can bring higher returns in the market than the positive ones.



(a) $D^a_{r\pm}$.

(b) $D^e_{r\pm}$.

(c) $D^a_{rrr\pm}$.

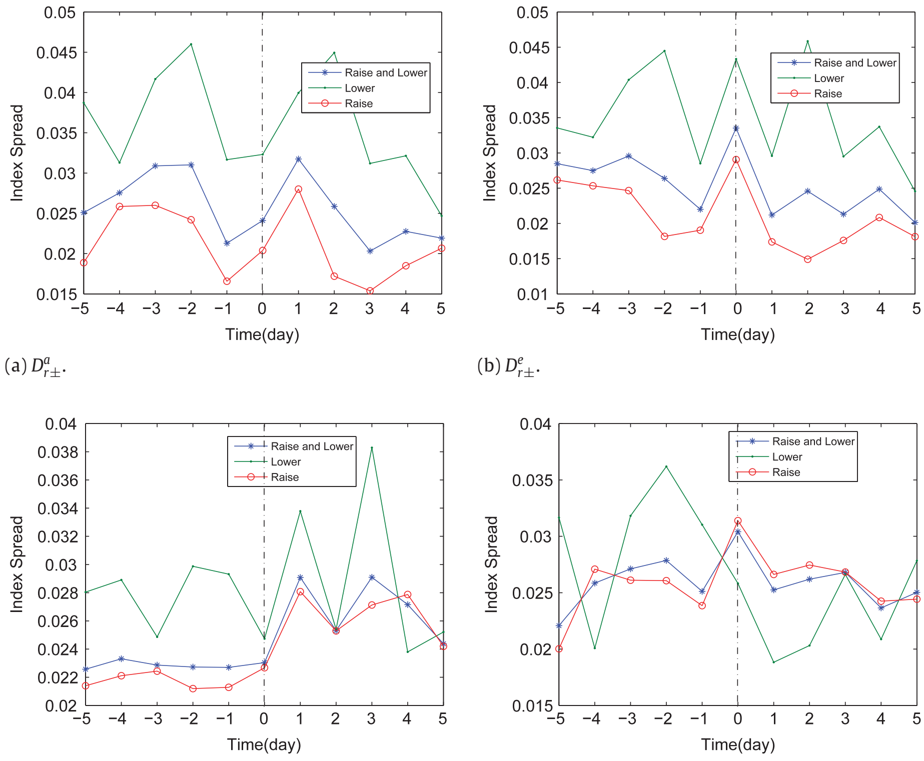
(d) $D^e_{rrr\pm}$.

Fig. 8. (Color online) Shanghai stock index returns are averaged over all 11 days, the time window of all event dates for the 4 date sets $D^a_{r\pm}$, $D^a_{r\pm}$, $D^a_{r\pm}$ and $D^a_{r\pm}$ in (a)–(d) respectively. First, from these figures, we see that for lowering r and rrr, the index returns have a sharp climb after the event date (Time $= 0$) and when Time $\geq$: $eq6$ the return gets larger than the raising curve, see (a)–(c), in other words, when the PBC lowers r or rrr, after the events dates, the market returns are getting higher when they are raised. This agrees with many literatures in that the lowering policy can boost the market, bringing higher market returns and this will happen with a delay of about 2–3 trading days. Second, the three curves of lowering ($-$, in green), raising ($+$, in red) and both ($\pm$, in blue) in each figure share a similar fluctuating shape. This indicates that the market has a similar response dynamics in responding to the lowering or raising of r or rrr, while the dynamics are unknown. For $D^a_{r\pm}$ and, the returns reach the lowest before the event dates on Time $= -3$. The raising curves (in red) stay above the lowering curves (in green), this seems in contrast with the signal effect, but it must be mentioned that the market is in a bear period with relative lower returns, while the raising events normally happened during a bull period or at least not in crash periods.

To investigate the volatility of the Shanghai market, we use the daily spread between the daily highest price and daily lowest price, the spread of the ith day of date set D is defined as,

$$\langle I_{\text{spread},i}(t)\rangle = \frac{\sum_{t\in D, t=i} I_{\text{spread}}(t)}{|D|}, \tag{11}$$

where $i = -5\cdots 5$. By averaging the daily $\langle I_{\text{spread},i}(t)\rangle$ and plotting in Fig. 9(a)–(d), we can observe that the curves in each time window of all 4 date sets $D^a_{r\pm}$, $D^e_{r\pm}$, $D^a_{rrr\pm}$ and $D^e_{rrr\pm}$ share a similar shape and there is a decline of volatility before event dates where Time $= 0$ which is agreement with the phenomenon of calm before storm in Ref. [15] of Irish stock market, in which the author reported that there appears to be a decline in volatility on the day prior to an FOMC meeting and a subsequent increase in volatility after the results of the FOMC meeting are made known. The spread reaches a peak on Time $= -2$, namely two days before the event dates and falls to the lowest point on the day on Time $= -1$, then followed by a fluctuation and reaching a peak again on Time $= 1, 2$, 1 or 2 days after the event dates. This shows there is a mechanism of the market response to the monetary changes but the details remain unknown. But it is worth pointing out that this so-called calm before the storm effect is not always true, since some major market changes might also occur after a period of high volatility. Also we find that in each date set as shown in Fig. 9(a)–(d), the curves of negative changes of lowering R or RRR are above the positive changes of raising R or RRR, which is exactly the same period of stock market crash, where in the lowering changes period of June 2008 to December 2008, the Shanghai index dropped straight from about 3000 to only 1800 in 6 months, as was also seen in the global financial crisis of 2008. These negative changes of monetary policy in the Chinese bear market are in agreement with some studies revealing that monetary changes can have asymmetric effects on the stock market, in other words, in bear markets, empirical evidence has been found that the S&P500 index has a larger fluctuation in the bear market than in the bull market [6,41,42]. Similar results also show raising or lowering changes in federal funds futures can have asymmetric effects on the stock market [43]. The sentiment of the markets during



(a) $D^{a}_{r\pm}$. (b) $D^{e}_{r\pm}$. (c) $D^{a}_{rrr\pm}$. (d) $D^{e}_{rrr\pm}$.

Fig. 9. (Color online) The daily spreads, $I_{\text{spread}} = \ln I_{high} - \ln I_{low}$, are averaged over all event dates and are plotted in the 11 dates time window for all 4 dates sets $D^{a}_{r\pm}$, $D^{e}_{r\pm}$, $D^{a}_{rrr\pm}$ and $D^{e}_{rrr\pm}$ in (a)–(d) respectively. The first interesting pattern we found in these figures is that for each date set, the three curves of raising (+, in red), lowering (−, in green) and raising–lowering (±, in blue) have a similar shape. For example, in (a), for all three curves, the $\langle I_{\text{spread}} \rangle$ experience a climb and reach a peak two days before the announcing date when Time $= -2$, then reach a lowest bottom when Time $= -1$ afterwards and climb again and reach a peak on the following day when Time $= 1, 2$. In other words, the market responds to the monetary policy changes in a similar dynamics mechanism even it remains unknown. Also, we can find an even more interesting pattern in that the $\langle I_{\text{spread}} \rangle$ of lowering (−, in green) events of R or RRR are larger than of the raising (+, in red) events, this is quite different from the cases for the $\langle I_{\text{return}} \rangle$ as shown in Fig. 8(a)–(d) where the raising curves are above the lowering curves. This actually is due to the fact that the period of lowering R and RRR is the same period as the stock market crash and the global financial crisis around 2008. The stock market has a different response than the monetary market in the short run.

a bear time, like a recession or tight credit conditions is more sensitive to monetary news and can lead to a stronger and larger fluctuation in the market [44]. Compared with the SHIBOR monetary market where the monetary changes bring clear fluctuation changes before and after event dates as shown in Fig. 7(a)–(f), the Shanghai stock market is also influenced by the monetary changes as shown in Figs. 8 and 9.

4. Conclusion

Monetary policy changes of central banks are the most major factors influencing the monetary market and financial market. The interest rate R and required reserve ratio RRR are the two most powerful tools used by the Chinese central bank, the People's Bank of China to adjust the markets and economy by lowering the rates to provide more money into the market to boost and stimulate the economy or by raising the rates to tighten the money supply to cool down the economy and fight inflation. Unlike the FED which announces the adjustment of rates in scheduled FOMC meetings, PBC announces raising or lowering of R and RRR as surprises without any schedules. This kind of surprise can shock both the monetary market and stock market. By analyzing all the 50 monetary policy changes of RRR and R in our study period between 2006-10-08 and 2012-05-11, and using the SHIBOR market prices and Shanghai stock market index price data, we study how the Chinese monetary policy changes impact the monetary market and stock market in China.

We construct the correlation matrices using the panel bank quotation level data and studied the largest eigenvalue distribution. We find that the SHIBOR market is closely related with the macro economy market. Our further study shows that the monetary changes of RRR and R have a great influence on the SHIBOR market and the stock market. Through studying the fluctuation of SHIBOR overnight interest rates on event dates, in Table 1, we find significant fluctuations in the SHIBOR market on event dates, and that on all event dates $D^{a,e}_{rrr\pm,r\pm}$, the $\langle \sigma \rangle = 0.0501$ and $\langle \text{spread} \rangle = 0.1963$ are almost twice the $\langle \sigma \rangle = 0.0257$ and $\langle \text{spread} \rangle = 0.0992$ for all the dates in our study period *ALL*. If the panel banks have no inside information or predictive ability regarding a monetary change surprise, then there should not be a large difference in fluctuations for

ALL and $D^{a,e}_{rrr\pm,r\pm}$. These findings show that the SHIBOR market is very sensitive to the impact of monetary changes of PBC, and based on the observed behaviors of panel banks, it seems that the SHIBOR market has a certain predictive ability for potential changes, but this needs more careful study and it would be a worthy topic of further investigation. Also, from Table 1, we find that the raising of RRR or R leads to larger fluctuations in the SHIBOR market than the lowering changes. This result agrees with the "sign effect" [25,12] in which bad news has a greater impact than good news on the market, in our case, the raising of RRR or R is bad news for the market because this kind of change means the PBC wants to tighten the money supply and bring larger fluctuations to the market, while the lowering of RRR or R means more liquidity and money supply to the market which is good news and brings smaller fluctuations. By constructing an event window with a size of 11 trading days, we also study how SHIBOR responds before and after the each monetary change. The averaged fluctuations $\langle\sigma\rangle$ of the SHIBOR market before and after the event dates are presented in Fig. 7. We again find clear "sign effect" where all $\langle\sigma\rangle$ of raising of R or RRR are higher than those of lowering of R or RRR over all date sets from $D^{a}_{r\pm}$ to $D^{e}_{rrr\pm,r\pm}$ as shown in Fig. 7(a)–(f).

The monetary policy changes can also have a great influence on the stock market. In order to study how the changes can impact the stock market, we use the daily Shanghai index data and build an event time window of the same length to see how the stock market responds differently before and after the event dates. As plotted in Fig. 8 for the index return and Fig. 9 for the volatility respectively, we find that the market returns will climb up with about a 3 day delay in the Shanghai stock market after the lowering monetary changes happen, and this is agreement with the effect that a market friendly policy, i.e. lowering the rate providing more money to the market, will bring about high returns. However, this will not happen immediately, but only with about a 3 day delay on average which indicates that the stock market slowly digests the monetary policy impact and reacts correctly. Also, we find that the volatilities of the Shanghai market, indicated as a daily spread of index return, as shown in Fig. 9, are influenced by the changes differently from the SHIBOR monetary market too. In the stock market, the volatilities of lowering changes are larger than that of raising changes, while for the SHIBOR market, the fluctuations of SHIBOR prices are the opposite, that raising R or RRR will bring larger fluctuations than lowering the rates. The reason behind this is that the period when PBC lowered the R or RRR was actually the bear market period of around 2008 when the market experienced a large crash. This is actually in agreement with previous studies, which found monetary policy changes during bad times or in a bear market might lead to larger volatility and fluctuations in the stock market [6,12,41,42].

Recently, many studies have emphasized the applicability and how the empirical findings can be valuable for policymakers [45]. Here we show that monetary policymakers must pay serious attention to how both the monetary market and stock market are impacted by the monetary policy changes [46], especially in a country like China where the economy is booming and the monetary changes are announced to the market as surprises with no pre-decided schedules. The stock market fluctuation is determined by the demand and supply shocks as well as the monetary policy changes [3], the findings suggest that in the short run time window of monetary changes, the market is influenced by the changes and demonstrates different behaviors in bear and bull markets to different monetary policies, either lowering or raising RRR and R. PBC is responsible for setting the R and RRR and it plays the same role as FED, which attracted much criticism for not doing enough to keep the economy healthy or even causing bubbles [47]. The empirical studies revealed would be useful to understand the relationship between the market and policy changes, and are also useful for the policymakers to monitor and evaluate the effect of monetary changes to the monetary market and stock market, since the stock market is a monetary policy transmission channel [23].

Acknowledgments

We thank the anonymous reviewers for their comments and suggestions, which helped us improve this work. We also wish to thank Liang Zhang for interesting discussions, and we are thankful for the financial support from National Science Foundation of China under grant No. 71172095 and Ministry of Science and Technology of the People's Republic of China under grant No. 2011IM020100.

References

[1] P. Sellin, Monetary policy and the stock market: theory and empirical evidence, Journal of Economic Surveys 15 (2001) 491–541.
[2] M. Farka, The effect of monetary policy shocks on stock prices accounting for endogeneity and omitted variable biases, Review of Financial Economics 18 (2009) 47–55.
[3] D. Du, Monetary policy, stock returns and inflation, Journal of Economics and Business 58 (2006) 36–54.
[4] L.T. He, Variations in effects of monetary policy on stock market returns in the past four decades, Review of Financial Economics 15 (2006) 331–349.
[5] H.C. Bjørnland, K. Leitemo, Identifying the interdependence between US monetary policy and the stock market, Journal of Monetary Economics 56 (2009) 275–282.
[6] S.-S. Chen, Does monetary policy have asymmetric effects on stock returns? Journal of Money, Credit & Banking 39 (2007) 667–688 (Wiley-Blackwell).
[7] N. Gospodinov, I. Jamali, The effects of federal funds rate surprises on S&P 500 volatility and volatility risk premium, Journal of Empirical Finance 19 (2012) 497–510.
[8] B.T. Ewing, Monetary policy and stock returns, Bulletin of Economic Research 53 (2001) 73.
[9] J. Scharler, Bank lending and the stock market's response to monetary policy shocks, International Review of Economics and Finance 17 (2008) 425–435.
[10] W. Thorbecke, On stock market returns and monetary policy, Journal of Finance 52 (1997) 635–654.
[11] S. Vähämaa, J. Äijö, The Fed's policy decisions and implied volatility, Journal of Futures Markets 31 (2011) 995–1010.
[12] A.M. Petersen, F. Wang, S. Havlin, H.E. Stanley, Quantitative law describing market dynamics before and after interest-rate change, Physical Review E 81 (2010) 066121.

[13] A.M. Petersen, F. Wang, S. Havlin, H.E. Stanley, Market dynamics immediately before and after financial shocks: quantifying the Omori, productivity, and Bath laws, Physical Review E 82 (2010) 036114.
[14] F. Allen, Financial structure and financial crisis, International Review of Finance 2 (2001) 1–19.
[15] D. Bredin, C. Gavin, G. O'Reilly, US monetary policy announcements and Irish stock market volatility, Applied Financial Economics 15 (2005) 1243–1250.
[16] D. Bredin, S. Hyde, D. Nitzsche, G. O'Reilly, European monetary policy surprises: the aggregate and sectoral stock market response, International Journal of Finance & Economics 14 (2009) 156–171.
[17] N. Cassola, C. Morana, Monetary policy and the stock market in the euro area, Journal of Policy Modeling 26 (2004) 387–399.
[18] O. Fernandez-Amador, M. Gächter, M. Larch, G. Peter, Monetary policy and its impact on stock market liquidity: evidence from the euro zone, Working Papers, Faculty of Economics and Statistics, University of Innsbruck, February 2011.
[19] S.M. Hussain, Simultaneous monetary policy announcements and international stock markets response: an intraday analysis, Journal of Banking & Finance 35 (2011) 752–764. Australasian finance conference: global financial crisis, international financial architecture and regulation.
[20] K. Kholodilin, A. Montagnoli, O. Napolitano, B. Siliverstovs, Assessing the impact of the ECB's monetary policy on the stock markets: a sectoral view, Economics Letters 105 (2009) 211–213.
[21] C. Ioannidis, A. Kontonikas, The impact of monetary policy on stock prices, Journal of Policy Modeling 30 (2008) 33–53.
[22] Y.D. Li, T.B. Iscan, K. Xu, The impact of monetary policy shocks on stock prices: evidence from Canada and the United States, Journal of International Money and Finance 29 (2010) 876–896.
[23] J.B. Durham, The effect of monetary policy on monthly and quarterly stock market returns: cross-country evidence and sensitivity analyses, in: Board of Governors of the Federal Reserve System, (US), in: Finance and Economics Discussion Series, 2001.
[24] D. Dickinson, J. Liu, The real effects of monetary policy in China: an empirical analysis, China Economic Review 18 (2007) 87–111.
[25] T.G. Andersen, T. Bollerslev, F.X. Diebold, C. Vega, Micro effects of macro announcements: real-time price discovery in foreign exchange, American Economic Review 93 (2003) 38–62.
[26] Monetary policy of the people's bank of China, July 2012. http://www.pbc.gov.cn/publish/english/957/index.html.
[27] Shanghai Interbank Offered Rate (SHIBOR) of Chinese Commercial Banks, July 2012. http://www.shibor.org.
[28] R. Mantegna, Hierarchical structure in financial markets, The European Physical Journal B—Condensed Matter and Complex Systems 11 (1999) 193–197.
[29] L.S. Junior, I.D.P. Franca, Correlation of financial markets in times of crisis, Physica A: Statistical Mechanics and its Applications 391 (2012) 187–208.
[30] D.-M. Song, M. Tumminello, W.-X. Zhou, R.N. Mantegna, Evolution of worldwide stock markets, correlation structure, and correlation-based graphs, Physical Review E 84 (2011) 026108.
[31] G. Livan, L. Rebecchi, Asymmetric correlation matrices: an analysis of financial data, The European Physical Journal B—Condensed Matter and Complex Systems 85 (2012) 1–11.
[32] G. Tilak, T. Széll, R. Chicheportiche, A. Chakraborti, Study of statistical correlations in intraday and daily financial return time series, in: F. Abergel, B.K. Chakrabarti, A. Chakraborti, A. Ghosh (Eds.), Econophysics of Systemic Risk and Network Dynamics, in: New Economic Windows, Springer, Milan, 2013, pp. 77–104.
[33] L. Sandoval Junior, Cluster formation and evolution in networks of financial market indices. ArXiv e-prints arXiv:1111.5069.
[34] G. Oh, C. Eom, F. Wang, W.-S. Jung, H.E. Stanley, S. Kim, Statistical properties of cross-correlation in the Korean stock market, The European Physical Journal B 79 (2011) 55–60.
[35] A.N. Bomfim, Pre-announcement effects, news effects, and volatility: Monetary policy and the stock market, Journal of Banking & Finance 27 (2003) 133–151.
[36] M.S. Rozeff, Money and stock prices: market efficiency and the lag in effect of monetary policy, Journal of Financial Economics 1 (1974) 245–302.
[37] T. Davig, J.R. Gerlach, State-dependent stock market reactions to monetary policy, International Journal of Central Banking 2 (2006) 65–83.
[38] M. Ehrmann, M. Fratzscher, Taking stock: monetary policy transmission to equity markets, Journal of Money, Credit & Banking 36 (2004) 719–737 (Ohio State University Press).
[39] T. Mann, R.J. Atra, R. Dowen, US monetary policy indicators and international stock returns: 1970–2001, International Review of Financial Analysis 13 (2004) 543–558.
[40] J. Tobin, A general equilibrium approach to monetary theory, Journal of Money, Credit and Banking 1 (1969) 15–29.
[41] D.W. Jansen, C.-L. Tsai, Monetary policy and stock returns: financing constraints and asymmetries in bull and bear markets, Journal of Empirical Finance 17 (2010) 981–990.
[42] A. Kurov, Investor sentiment and the stock market's reaction to monetary policy, Journal of Banking & Finance 34 (2010) 139–149.
[43] O. David Gulley, J. Sultan, The link between monetary policy and stock and bond markets: evidence from the federal funds futures contract, Applied Financial Economics 13 (2003) 199.
[44] A. Basistha, A. Kurov, Macroeconomic cycles and the stock market's reaction to monetary policy, Journal of Banking & Finance 32 (2008) 2606–2616.
[45] B. Podobnik, D. Horvatić, D.Y. Kenett, H.E. Stanley, The competitiveness versus the wealth of a country, Scientific Reports 2 (2012).
[46] B. Bernanke, M. Gertler, Monetary policy and asset price volatility, Economic Review 84 (1999) 17–51.
[47] S.F. England, The Federal reserve board and the stock market bubble, Business Economics 38 (2003) 33.