The onshore-offshore interaction of RMB market: a high-frequency analysis

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Abstract

With 10-minute data from Nov 2014 to Jan 2015, a threshold autoregression (TAR) model is estimated to assess the exchange rate differential between onshore and offshore RMB market, and the following result is in order. (i) The threshold effect is verified during sample period, around 40 bps on average. (ii) The persistence of onshore/offshore gap is quite similar across regimes, even after some policy change on capital control. (iii) Beyond threshold level, external volatility becomes important determinant of the exchange rate differential. The announcement effect of median price on offshore market is also proved from tick data.

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China has been trying to promote RMB internationalization since the 2008 financial crisis. Several steps are taken to increase the use of RMB in trade and finance. First, China's central bank (PBOC) signed and renewed currency swap agreement with several developing and industrialized countries. Second, RMB is encouraged in cross-border trade as settlement currency. Thirdly, offshore RMB (CNH) market experienced a fast development in Hong Kong, Taiwan, Singapore and other regions. Finally, China is in a gradual process of capital account liberalization, facilitated by outward FDI and Asian Infrastructure Investment Bank (AIIB).

Among these, CNH market is interesting for at least two reasons. Traditional offshore market, such as Eurodollar market, was established mainly to expand business hour and escape regulation, so government wouldn't foster its development. In contrast, CNH market was officially launched in a high-profile manner, and it's regarded as an experiment field for further financial reform in mainland China. Furthermore, the segmentation of onshore (CNY) and offshore (CNH) market leads to different exchange rate for the same currency, which is nothing new for China where the ideology of 'one country, two system' is widely adopted. Then what factor, other than capital control and transaction cost, could explain this differential? Does it have a mean-reverting tendency if the gap is too big or arbitrage too prevalent? These and other related topics would be discussed with the help of TAR model. A good understanding of this exchange rate differential is also important for policy makers and investors to extract more useful information. Although free from government intervention, CNH market is relatively constrained in liquidity and susceptible to external volatility. A careful examination of CNY/CNH gap illustrates the difference of two markets and helps forecast the future.

In addition to arbitrage and carry trade, the interaction between CNY and CNH market is also attributed to common shock and information spillover. The release of macro data, for example, would provide guidance and influence both markets. The institutional setup of median price provides a natural experiment to identify this process. After median price is announced, investors in CNH market has 15 minutes to collect information and build position before actual arbitrage. Thanks to the availability of tick data, I would inspect this announcement effect by a statistical summary.

The main finding from TAR model estimation is the following. First, threshold effect is verified during sample period between Nov 2014 and Jan 2015. Specifically, investors would engage in arbitrage when CNH is weaker than CNY by over 40 bps. Secondly, the persistence of exchange rate differential doesn't change significantly across regimes, rejecting a strong mean-reverting tendency. This is a little surprising given the policy change on capital control, especially the launch of Shanghai-Hong Kong stock connect program. Thirdly, external volatility such as VIX becomes important determinant when CNY/CNH gap is beyond threshold level. As for the announcement effect, a statistical summary shows that liquidity and volatility in CNH market is hugely influenced by median price, at least within 5 minutes after its release.

For the rest of this paper, part 1 briefly depicts institutional background; part 2 describes various methods of arbitrage and carry trade between two markets; part 3 shows the result of TAR estimation; part 4 is a statistical summary of announcement effect for median price, and part 5 concludes.

1 Institutional background

Table 1 summarized the institutional difference between onshore and offshore market. Interested reader could refer to Funke et al. (2015) and Zhang et al. (2013) for detail. Some recent developments in 2014 are noteworthy here.

The onshore RMB market has been dominated by one-way bet since its re-liberalization in 2010, but that trend was toppled in March 2014 when PBOC widened the daily trading band to 2%, and, according to the data later released, engaged in direct FX intervention to make CNY depreciate. The short-term effect was a blow on arbitrage and speculation, while the long-run consequence was a call for more sophisticated financial product to meet firm's hedging demand. For example, the standardized FX option was not given enough attention until after this turmoil. Not surprisingly, market liquidity and sophistication had a significant improvement in both onshore and offshore market since then.

This move also signified a great change of monetary policy: PBOC regained the freedom of issuing money through loan and other instrument rather than

subject to exchange rate target, which means onshore market would be more susceptible to external volatility. That's probably one reason for the intimate interaction between onshore and offshore market. It must be cautioned, however, that PBOC's exit of direct intervention doesn't imply a perfect competitive FX market, since the median price, daily trading band, and market participants remain under regulation. By setting the median price at a preferred level, PBOC could limit exchange rate volatility within a certain range, and the threat to intervene around the upper or lower daily trading bound still constrained onshore FX trade.

2 Arbitrage and carry trade in RMB market

For the sake of definition, arbitrage is the market activity due to exchange rate differential between onshore and offshore RMB market, while carry trade stems from interest rate differential. These activities first came under academic scrutiny probably in December 2011, when liquidity drain and deleverage effect in offshore market leads to a dramatic shift in onshore market, which is dubbed as '12 days of consecutive depreciation'. Yu (2012) is a pioneering work that discussed the micro-foundation of this phenomenon and studied the onshore-offshore link. A lot of empirical papers ensued and documented the related mechanism and channels so that the picture is relatively clear now.

In practice, the existence of exchange rate and interest rate differential alone is not enough. A successful arbitrage also requires a partner in offshore market and a bank with long-run relationship to reduce transaction cost. The profit of arbitrage or carry trade would be shared by parent company in onshore market, partner in offshore market, and the banking system, therefore a systematic and stable trading strategy must be established so that a small but sustainable revenue could be guaranteed.

The following section is a summary of three main channels of arbitrage and carry trade between onshore and offshore market. For simplicity, assume RMB is stronger in offshore market, and interest rate is higher in onshore market; RMB is regarded as home currency and USD is foreign currency. The direction of operation would be reversed if the underlying relationship of exchange rate or interest rate is altered.

Channel 1: arbitrage due to exchange rate differential

Under current account transaction, Chinese exporter and importer could always choose a favorable price for currency conversion. When RMB is stronger in offshore market and USD is stronger in onshore market, exporter would convert USD into RMB in onshore market and importer would convert RMB into USD in offshore market. There is another arbitrage opportunity with similar procedure and dubbed as 'one-day trip to Hong Kong'. These arbitrage activities should decrease the exchange rate differential.

- Step 1: onshore company imports from offshore subsidiary, and pays RMB.
- Step 2: offshore subsidiary converts RMB into USD at the favorable offshore price.
- Step 3: offshore subsidiary imports from onshore company, and pays USD.
- Step 4: onshore company converts USD into RMB at the favorable onshore price.

Channel 2: carry trade due to interest rate differential

In principle, China's capital control should eliminate any carry trade opportunity, but corporations have come up with numerous ways to bypass this restriction, with one of the most popular known as 'onshore collateral and offshore loan'.

- Step 1: onshore company makes a long-term deposit in onshore bank, enjoying a relatively high level of onshore interest rate.
- Step 2: onshore company imports from offshore subsidiary and pays with RMB letter of credit issued by onshore bank, using its onshore deposit as collateral.
- Step 3: offshore subsidiary shows letter of credit to bank, and gets RMB loan at a relatively low level of offshore interest rate.
- Step 4: offshore subsidiary imports from onshore company, pays RMB with the proceeds from offshore loan.

- Step 5: onshore company reaps profit generated from the gap between onshore saving rate and offshore loan rate

Channel 3: combo of arbitrage and carry trade

The third channel is a simple continuation of channel 2, taking advantage of both exchange rate and interest rate differential.

- Step 1: onshore company makes a long-term deposit in onshore bank, enjoying a relatively high level of onshore interest rate.
- Step 2: onshore company imports from offshore subsidiary and pays with RMB letter of credit issued by onshore bank, using its deposit as collateral.
- Step 3: offshore subsidiary shows letter of credit to bank, and gets USD loan at a relatively low level of offshore interest rate and a favorable level of offshore exchange rate.
- Step 4: offshore subsidiary imports from onshore company, pays USD with the proceeds from offshore loan.
- Step 5: onshore company either waits for the due date or locks exchange rate risk by forward contract. It reaps profit from both interest rate and exchange rate differential, given that onshore saving rate is higher than offshore loan rate, and onshore RMB has a tendency of further appreciation.

3 A TAR approach to onshore-offshore gap

This section would apply threshold auto-regression (TAR) model to the onshore/offshore exchange rate differential and discuss its property as well as determinant.

3.1 Related literature

Empirical papers on the interaction between onshore and offshore RMB market didn't flourish before 2012, since CNH market liquidity was heavily constrained in its years of inception. After China became determined to make

RMB international and officially promoted its use as cross-border trade settlement currency, RMB deposit in Hong Kong and trade volume in CNH market skyrocketed.

Some research focused on the price discovery process and tried to find out which market is more important in determining exchange rate. The common approach is applying vector error-error correction model (VECM) or generalized auto-regression conditional heteroskedasticity (GARCH) model to daily or intra-day trade data, and calculate the contribution to price discovery based on Hasbrouck (1995). For example, Zhu and Liu (2012) examined intra-day trade data from April to November in 2011, and reached the conclusion that onshore market, especially median price, is dominant in the price discovery process.

Another strand of literature used order flow to discuss the micro-structure of CNY and CNH market. The success of order flow in explaining high-frequency exchange rate movement received a lot of attention since Evans and Lyons (2002). The performance of order flow in RMB FX market, however, is far from satisfactory. Zhang (2013) examined order flow in CNY market with daily data, but R^2 was only 10% at most, even when taking government intervention and country risk premium into consideration, quite a long way from 66% in Evans and Lyons (2002), which might result from the frequent and heavy PBOC intervention during that period. Zhang et al. (2013) used daily data between December 2009 and June 2011, and estimated a vector auto-regression (VAR) model. They found that order flow could explain about 19% of daily exchange rate volatility in CNY market. For offshore market, Cheung and Rime (2014) examined the effect of daily order flow in offshore market between September 2010 and August 2013. They found that CNH order flow affects CNY variation, and median price was still important in directing CNH and CNY movement.

The empirical literature mentioned above discussed onshore/offshore interaction but was silent about the property of price differential, which is systematically assessed in Funke et al. (2015) with daily data from September 2010 to September 2013. In the framework of extended GARCH, the determinant of price differential was found to include market liquidity (e.g. bid/ask spread), stock price, policy change variables, while global risk aver-

sion (e.g. VIX) tend to increase the volatility of this differential. Notwithstanding its considerable merits, the empirical analysis based on daily data might overlook some intra-day dynamics. Moreover, in 2014, financial press often reported that arbitrage between CNY and CNH market would happen only when price gap reached a certain level, since transaction cost would make arbitrage unprofitable otherwise. This observation naturally leads to the adoption of threshold auto-regression (TAR) for further analysis on intra-day data.

First proposed in Tong and Lim (1980), TAR model has become a popular approach to nonlinear time series data. The basic assumption is that linear relationship would significantly change when switching from one regime to another, determined by the level of threshold variable. Among its wide application, TAR model is heavily utilized to discuss price movement, see Taylor (2001) for the debate on purchasing power parity and Jacks (2006) for commodity price convergence. Craig et al. (2013) applied an asymmetric self-excited threshold auto-regression (SETAR) model to the daily CNY/CNH price differential from September 2010 to January 2013, and found limited integration between CNY and CNH market. This paper would estimate a TAR model with exogenous variables to discuss the intra-day dynamics between these two markets.

3.2 A TAR analysis on CNY/CNH gap

3.2.1 Empirical framework

The regression to be estimated in this part is the following.

$$y_{d,t} = \beta_1 y_{d,t-1} + \boldsymbol{\beta_2 X_{d,t}} + \boldsymbol{\beta_3 X_d} + C + \epsilon_{d,t} \ ,$$

where the dependent variable $y_{d,t}$ is the exchange rate differential between CNY and CNH market, with subscript of day d and time t. The independent variables include the lag of exchange rate differential ($y_{d,t-1}$), vector of intra-day explanatory variables ($X_{d,t-1}$), daily explanatory variables (X_d), and constant C. In this case, $y_{d,t-1}$ is also treated as threshold variable that would determine the regime in TAR model. Therefore the specific form of TAR estimation is

$$y_{d,t} = \begin{cases} \beta_1^1 y_{d,t-1} + \boldsymbol{\beta_2^1 X_{d,t}} + \boldsymbol{\beta_3^1 X_d} + C^1 + \epsilon_{d,t} & \text{if } \ y_{d,t-1} \leq q \\ \beta_1^2 y_{d,t-1} + \boldsymbol{\beta_2^2 X_{d,t}} + \boldsymbol{\beta_3^2 X_d} + C^2 + \epsilon_{d,t} & \text{if } \ y_{d,t-1} > q \end{cases}$$

where the superscript of coefficient is the index for regime, and q is the threshold level to be estimated. Since the lag of dependent variable is regarded as threshold variable, this regression is SETAR(1) model, with additional exogenous variables of $\boldsymbol{X_{d,t}}$ and $\boldsymbol{X_d}$.

3.2.2 Data description

The sample period for TAR estimation is from Nov 3, 2014 to Jan 23,2015, with the following considerations.

The starting point is Nov 3, 2014 thanks to several meaningful policy changes. First, Shanghai-Hong Kong stock connect program was launched in Nov 17 that allows Hong Kong investors to participate in Shanghai Stock Exchange. This reform attests to China's determination to liberalize capital account, and that should promote the integration between CNY and CNH market. Secondly, PBOC lowered interest rate for both savings and loans on Nov 21, confirming market's expectation that Chinese economy had downward pressure. This shock further reinforced the cycle of strong dollar, and CNH experienced accelerating depreciation afterwards.

The sample period ends on Jan 23, 2015 mainly for the volatility in Euro currency market. European Central Bank announced its plan of asset purchase on Jan 23, widely interpreted as the Euro version of quantitative easing. US dollar gained further strength, and European currency market had another round of turmoil after Swedish central bank canceled its limit on the Krona-Euro exchange rate on Jan 14. The seasonal factor of Chinese New Year also makes January an ideal time to conclude.

Table 2 is a summary of data source and description. The dependent variable is log difference of onshore and offshore exchange rate for every 10 minutes. Due to a cycle of strong dollar during sample period, CNH is weaker than CNY, therefore the gap is negative most of the time, and widening of the gap means a decrease of log difference. In addition to the auto-regressive component, intra-day exogenous variables include the following.

onshore trade volume An increase of trade volume in onshore market implies less of government intervention, and that would help close the gap, so its sign is expected to be positive.

offshore tick number A tick happens when traders change quote or order. If investors adjust quote too frequently, that implies an increase of uncertainty and volatility that would further widen the gap. So its sign is expected to be negative.

offshore bid/ask spread Bid/ask spread is a standard measure of market liquidity, and more liquidity should stabilize market and close the gap, so its sign is expected to be negative.

Daily exogenous variables include the following.

deviation from CIP This is an ex post measure of capital control. A strict capital control would certainly reduce the onshore-offshore interaction, but its sign is uncertain.

median price CNY market has a 2% daily trading band around median price. If onshore trade is limited by this restriction, interaction would be weak, but its sign is uncertain.

dollar index (DXY) A strong dollar would weaken both CNY and CNH, but government intervention and other restrictions would limit depreciation in onshore market, and that would widen the gap. So its sign is expected to be negative.

VIX and Euro VIX These measures capture external volatility. Cairns et al. (2007) found that heightened global volatility tend to depreciate high-yielding currencies and appreciate low-yielding currencies, which might be explained by 'fight to safety'. It is also verified by Kalra (2011) that found this relationship valid for Asian currencies. Moreover, VIX is related with carry trade, as discussed in Brunnermeier et al. (2008). Given the high-yielding performance of CNH during the past few years and its susceptibility to carry trade and speculation, an increase of external volatility would widen the gap. So the sign is expected to be negative.

The source of offshore data deserves some comments here. For a highly decentralized CNH market, electronic platform already made 24-hour trade possible. In contrast, CNY market is still confined to local business hour

from UTC 1:30 to 8:30. The offshore data in this paper is collected from an ECN (Electronic Community Network) FX platform in Switzerland, involving mainly Euro and Asian investors. It's necessary to check data quality by comparing it with CNHFIX, which is the average mid-quote of 18 banks in Hong Kong, publicized at UTC 3:00 every business day[1]. Figure 1 shows the histogram of difference between CNHFIX and the mid-quote from electronic platform, measured in bps during sample period. Data quality is acceptable, with most of the difference lying within 4 bps.

3.2.3 Single or multiple thresholds?

The TAR model in this paper assumes only one threshold, largely due to the selection of sample period. According to Yu (2012), when CNH is stronger than CNY, and onshore interest rate is higher than offshore interest rate, there should be two thresholds for CNY/CNH gap: if CNY and CNH are too close, carry trade would widen the gap; if the exchange rate differential is too big, arbitrage tends to close the gap. But the underlying relationship of exchange rate and interest rate is fundamentally reversed during sample period. Figure 2 depicts the intra-day movement of USDCNY and USDCNH, where CNY is stronger than CNH most of the time. Figure 3 shows the interest rate differential between onshore and offshore RMB market. Although the long-run interest rate is positive by only a small margin, the short-run interest rate doesn't show any clear pattern, and that would constrain the power of carry trade.

This observation is also supported by financial news during this period, which usually reports cycle of strong dollar and excessive external volatility leading to a dramatic depreciation in CNH market, and that shock is transmitted to CNY market through arbitrage[2]. Therefore, the assumption of one threshold effect is reasonable, at least for the sample period.

3.2.4 Regression result and robustness test

Before conducting regression analysis, it's necessary to check whether result from TAR is significantly different than linear regression. Hansen (1999)

[1] http://www.tma.org.hk/Fixing_Specification_for_Spot_USDCNY(HK)_Fixing_(20Jun14).pdf

[2] http://cn.reuters.com/article/2014/11/20/yuan-frx-market-idCNKCS0J410F20141120

advocated a F-test based on bootstrap distribution for this task. Figure 4 shows its result, and F sequence clearly exceeds 95% critical value, so linear estimation model should be rejected. Moreover, this F sequence shows a hump shape, indicating a strong threshold effect. Therefore, TAR model is a good choice to assess CNY/CNH gap.

Table 3 presents the benchmark regression. AR(1) model is first estimated for comparison, and a two-regime TAR model shows relatively different result. This difference mainly comes from exogenous variables rather than the auto-regressive component. The persistence of CNY/CNH gap is quite similar across regimes, and comparable to AR(1) estimation. Figure 5 shows the estimation of threshold level, and the gap is pretty persistent, although its behavior seems different across regimes. The estimation of threshold level is -6.38 in terms of log difference, about 40 bps in level.

As for the significant exogenous variables, liquidity and volatility are always important determinants. Consistent with expectation, onshore trade volume helps reduce gap while offshore volatility tends to widen it. This finding points to the necessity of further reform and liberalization for both markets. The sign of volatility index is interesting here because an increase of external volatility is expected to widen the gap, but the sign of VIX is positive. A possible explanation is that VIX only captures US market volatility, and investors find CNH more attractive when volatility heightened in US.

A brief look at figure 5 reveals some outliers at the beginning and end of each month, probably due to noise traders like large corporations and multinational enterprises who trade for fiscal reason during that period. Table 4 shows subsample robustness test by excluding the first and last business day of each month. The result is largely consistent with benchmark estimation. To further check robustness, SETAR(1) and stepwise regression are also estimated, and the result is in table 5. The independent variables in SETAR(1) include only auto-regressive component and constant, while stepwise regression uses only significant regressors in benchmark estimation. For SETAR(1) model, F-test against linearity is passed at 10% level, and the threshold level is -8.71, around 53 bps in level. The persistence of exchange rate differential proves still similar across regimes. Stepwise regression confirmed the robustness of findings from benchmark estimation, with an estimated threshold

level of -5.11, around 32 bps.

For further robustness check, I would estimate an extended GARCH(1,1) model, which is a standard toolkit for high-frequency data. The specific form is

$$y_t = \beta y_{t-1} + \gamma X_t + C + \epsilon_t$$
$$\sigma_t^2 = \alpha_1 \epsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2 + \gamma_1 X_t' + \omega$$

where the first line is mean equation while second line is variance equation, with σ^2 as the variance of forecast error, and ω as a constant term. Because GARCH model requires a continuous sample, the threshold effect wouldn't be verified, and external volatility might be overlooked in the whole sample, but the importance of liquidity and volatility should hold still. Table 6 is the result from GARCH estimation. In addition to the crazy persistence of exchange rate differential, onshore volume and offshore volatility remain prominent in mean equation. From variance equation, GARCH effect is verified by the significance of ϵ_{t-1}^2 and σ_{t-1}^2. Furthermore, onshore volume has a stabilizing effect in reducing conditional variance, while offshore volatility shows a destabilizing effect.

3.2.5 Interpretation and discussion

The result from TAR estimation delivers several meaningful messages about the relationship between CNY and CNH market.

First, the threshold effect is verified during sample period, about 40 bps on average. This means arbitrage would probably happen when CNH is weaker than CNY by over 40 bps, roughly consistent with financial news, where traders reported that arbitrage turned active after the gap reached 50-60 bps. It should be cautioned, however, that threshold level is time-varying, possibly related with financing cost and capital control policy.

Secondly, the persistence of CNY/CNH gap is quite similar whether it's below or above threshold, attesting to the effectiveness of China's capital control. This observation agrees with Cheung and Herrala (2014), who used monthly data of CIP deviation from 1999 to 2012 to examine the degree of capital control, and reported that China's capital control is still substantial and effective, even after the global financial crisis.

The persistence of CNY/CNH gap posed a challenge for economic research. Traditional theory usually assumes that capital control and arbitrage are mutually exclusive: if a country adopts capital control, deviation from CIP should be persistent since there is no trade to eliminate arbitrage opportunity; if capital mobility is allowed, market activity should eradicate any price differential beyond the band of inaction. The case of China is in the middle ground: arbitrage and capital control exist at the same time. This probably results from the micro-structure of China's FX market. The arbitrage or carry trade between CNY and CNH market is still under the cover of current account transaction, which would definitely constrain the power of market activity in many dimensions. As shown in part 2, it's almost impossible for individual investor to bypass restriction since that requires a foreign partner, so the main participants in this market are state-owned enterprise and multinational corporations that have foreign subsidiaries and easy access to bank loans.

Last but not least, the determinant of CNY/CNH gap is different across regimes. If the gap didn't reach threshold level, both onshore and offshore factors are important in accounting for its intra-day movement. Beyond threshold level, onshore factor has only a weak effect, and the gap is mainly determined by offshore market activity and external volatility. which is also echoed in Funke et al. (2015). This change of determinant might come from central bank intervention in the offshore market or liquidity drain in offshore market.

4 The announcement effect of median price: a statistical summary

As shown in part 2 and 3, the interaction between CNY and CNH market could be attributed to market activity, but information spillover or common shock also has the potential to link onshore and offshore market. It's quite difficult to distinguish the effect of news shock from arbitrage during business hour, but the institution setup of CNY market provides a nice experiment to exam the information transmission process.

Recall that CNY market has a daily trading band of 2% around median price, which is announced at UTC 1:15, but onshore market opens only after UTC 1:30, therefore the period of UTC 1:15-1:30 provides a natural experiment on the announcement effect of median price. There is no arbitrage during this period, so any abnormal phenomenon in CNH market largely results from this news shock. If onshore and offshore markets are perfectly segmented by capital control, investors in CNH market wouldn't think too much of median price, which is no more than PBOC's preferred level of exchange rate. If, on the other hand, imperfect capital control brings two markets into considerable correlation, investors in CNH market would form new expectation and rebuild positions according to the change of median price, whose signal effect for onshore market remains substantial.

4.1 A 24-hour overview of CNH market

Before exploring the announcement effect, it's compelling to take advantage of tick data and retrospect on the chaos and turmoil in an eventful 2014.

At the risk of repetition, offshore tick data of quote in this paper comes from an electronic platform in Switzerland, involving mainly Asian and European investors. 24-hour trade is possible under this environment, but market activity is concentrated around the time when CNY (UTC 1:30-8:30)or Euro (UTC 8:00-16:00) market is most active. Figure 6 shows the hourly average of bid/ask spread from March 2014 to Jan 2015, all measured in bps. Bid/ask spread is a standard measure of financial market liquidity, and a big spread indicates worsening of liquidity condition. Within each single figure, the spread is relatively small during UTC 1-16, generally around 4 bps, and it has a great increase after Euro market closes, jumping to about 10 bps. From another perspective, the development of CNH market over time is also noticeable, with the normal spread reduced from 22 bps in March 2014 to 4 bps in Jan 2015.

Figure 7 is the hourly average of tick number, a proxy for financial market volatility. A tick would happen whenever traders adjust quote or order. If traders change quote or order too frequently, that implies an increase of volatility. Within each sub-figure, there is a clear pattern of U-shape during UTC 1:00-9:00, nicely echoing activities in CNY market, where a

break session during UTC 4:00-5:00 makes trade volume close to 0, while the most active period is usually around the open and close time. The U-shape in figure 7 indicates a close relationship between onshore and offshore investors.

Figure 8 is the hourly average of pseudo order flow in CNH market, defined as the difference between ask and bid volume. Different from order flow in Evans and Lyons (2002), here a positive pseudo order flow would suggest stronger supply pressure. One shocking feature of figure 8 is the directional change. Before July 2014, supply pressure was dominant in CNH market, but that changed into a more balanced picture afterwards, with stronger demand pressure after October 2014, probably resulting from investor's expectation. The CNY deprecation sponsored by PBOC around March melted down market's expectation of unilateral appreciation. This unexpected shock made investor uncertain about future, so the most reasonable strategy is to square position and avoid risk, leading to the strong supply pressure since March. In contrast, another round of RMB depreciation since October was mainly attributed to strong USD and the downward pressure of Chinese economy. For investors, this is an expected shock traceable from macro data and policy. Central bank intervention and daily trading band limited CNY depreciation, so investors would do arbitrage by acquiring RMB at low price in CNH market and dump it in CNY market to reap profit, leading to strong demand pressure for offshore RMB, especially during UTC 1-8 when CNY market is open.

Figure 9 shows summary statistics for sample period during Nov 2014 and Jan 2015, generally consistent with the above observation.

4.2 Announcement effect under high-resolution

With more high-frequency data available for research, investor's response to a certain shock could be examined more carefully. For example, Evans (2014) found out a mean-reverting tendency around WMR fix thanks to the availability of tick data. This section would take a similar approach to explore investor's behavior before and after the announcement of median price.

Figure 10 shows CNH market activity during UTC 1:00-1:30. The tremendous increase of bid/ask spread around 1:14-1:16 indicates liquidity drain.

Given the considerable uncertainty of central bank's attitude, investors and market makers are unwilling to trade at that time. From tick number, it's easy to find that market volatility hugely increased during 1:14-1:19. A reasonable interpretation is that investors would spend around 5 minutes collecting information, adjusting quote, and coming up with a new investment strategy. A reaction time of 5 minutes is also comparable with findings in finance literature. Figure 11 shows market condition during UTC 1:15-1:45 as another comparison. Obviously, the opening of CNY market reduced volatility and increased liquidity in CNH market.

Figure 12 plots the kernel density of mid-quote change around UTC 1:15, with blue solid line for pre-announcement change while red dashed line for after-announcement change. The wide dispersion of the latter suggests an increased level of volatility after announcement. This pattern also holds for other period in 2014, as confirmed in figure 13. Table 7 illustrates this point with summary statistics of quote changes per minute. For different time horizons, after-announcement quote change always has more volatility in terms of standard deviation, and two-sample Kolmogorov-Smirnov largely rejects the null hypothesis that pre and after announcement change comes from the same continuous distribution. Overall, investor's behavior changed after announcement, and market volatility greatly increased at least within 5 minutes.

Another aspect of announcement effect is whether median price has a signal effect to guide exchange rate movement. In other words, signal effect would work if, for example, median price was depreciated and investors followed suit to adjust quote. Given the importance of median price, market participants have come up with many methods to forecast its level, and one of the most popular instrument is USD index (DXY). The official exchange rate regime of RMB is (i) based on supply and demand, (ii) referring to a basket of currencies, and (iii) managed floating system. DXY is compiled from a basket of currencies, and median price should be predictable from DXY if central bank doesn't have any plan of intervention. Figure 14 is the mid-quote change per minute during UTC 1:00-1:30. The first two sub-figures illustrate a strong signal effect of median price for at least 5 minutes after its release, when mid-quote change generally followed its trend. On the other hand, DXY didn't do a good job in forecasting exchange rate movement. Therefore, it's still

median price, rather than DXY, that provided guidance and unified market expectation.

Given this announcement effect, it's tempting to forecast median price and do some arbitrage accordingly. Table 8 examines several investment strategy to inspect the exchange rate movement around UTC 1:15, for sample period during Nov 2014 and Jan 2015. One must caution, however, that previous discussion is mainly based on mid-quote, while this table tries to capture the real profit by using bid/ask price. If investor has confidence in offshore RMB, he would adopt strategy 1 to take long, otherwise strategy 2 of selling short is more favorable. If investor believes CNH market should follow the trend of DXY, he would build position according to strategy 4, otherwise he should follow strategy 3. Abstracting from transaction and financing cost, table 8 lists the average return and Sharpe ratio of different strategies. Obviously, selling short of RMB is the optimal choice in terms of investment performance. This result confirms the inability of DXY to forecast median price, and it also demonstrates the impact of strong dollar on CNH market.

In summary, the announcement effect of median price is verified in tick data, and it takes market at least 5 minutes to discover a new price and come back to normal. There is liquidity drain and increased volatility around announcement, and it's hard to do profitable arbitrage by forecasting median price.

5 Conclusion

At the heart of financial market is liquidity and volatility. Without liquidity, there's no meaningful price. Without volatility, there's no variety of price. A full-fledged market should reach both ends at the same time: abundant liquidity helps smooth fluctuation and provide confidence, while considerable volatility fosters financial derivatives to meet hedging and speculative demand. China's FX market, however, is in an odd position where CNY market has relatively richer liquidity but not enough volatility, whereas CNH market is dominated by excessive volatility due to the lack of liquidity. The integration of onshore and offshore market remains a long way ahead, even after the eventful year of 2014.

Future research could look more carefully at the micro-structure of China's FX market and discuss related policy issues. Should PBOC make median price more transparent, predictable, and market-driven? Should China abandon the real-bill doctrine in onshore market to improve liquidity and volatility? What's the proper road-map to reform domestic financial institution without incurring great loss from exchange rate mis-alignment or fluctuation? Finally, capital account liberalization is not the ultimate solution for every problem, so how to promote RMB internationalization with other complementary measures, and what's the role of CNH market in the future? With better theory and econometric tools, there's hope of answering these questions in a meaningful way.

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Table 1 Institution background

	CNY market	CNH market
product	mainly spot and forward; option and swap premature	spot, forward, option, swap
market participants	central bank state-owned bank subsidiaries of foreign banks finance companies	open to all investors
government intervention	Yes	No
daily trading band	2% around median price for interbank market; no limit on OTC market; median price largely controlled by PBOC	No
business hour	UTC 1:30-8:30 for interbank market	24-hour
daily turnover in April 2013		
spot	USD 20 billion	USD 13.9 billion
deliverable forward	USD 2.6 billion	USD 8.4 billion
bid/ask spread (2013 Q4)	17 bps	33 bps

Source: adjusted from Funke et al. (2015), daily turnover and bid/ask spread from BIS Triennial Survey and Bloomberg

Table 2 Data description

Name	Description	expected sign	Source
$y_{d,t}$	$y_{d,t} \equiv (\ln S^{on} - \ln S^{off}) * 10000$ S^{on} is onshore spot rate S^{off} is offshore mid-quote close price of every 10 minutes both expressed in RMB per USD	+	www.chinamoney.com.cn www.dukascopy.com
onshore trade volume	in log form	+	www.chianmoney.com.cn
offshore tick number	A tick happens when trader adjust quote or order A proxy for market volatility	-	www.dukascopy.com
offshore bid/ask spread	$(\ln S^{\text{ask}} - \ln S^{\text{bid}}) * 10000$	-	www.dukascopy.com
Deviation from CIP	$\frac{S^{on}}{NDF}(1 + i_{\text{SHIBOR}}) - (1 + i_{\text{LIBOR}})$ NDF is 1 year non-deliverable forward of RMB per USD i_{SHIBOR} is 1 year SHIBOR rate i_{LIBOR} is 1 year LIBOR USD rate close price of previous day	?	www.chinamoney.com.cn cn.reuters.com FRED
CNY median price	announced at UTC 1:15 in log form	?	www.chinamoney.com.cn
USD index (DXY)	in lag	-	FRED
VIX	measurement of US volatility in lag	-	FRED
Euro VIX	measurement of Euro volatility in lag	-	FRED

Table 3 Benchmark estimation

	AR(1)	TAR estimation Regime 1	TAR estimation Regime 2
$y_{d,t}$			
		$y_{d,t-1}$ ≤-6.38	$y_{d,t-1}$ >-6.38
$y_{d,t-1}$	0.92***	0.87***	0.85***
onshore volume (d,t)	0.09***	0.06*	0.15***
offshore tick number (d,t)	-0.48***	-0.39***	-0.57***
offshore bid/ask spread (d,t)	0.04 *	0.18	-0.18
Deviation from CIP (d-1)	-0.93	0.92	0.4
CNY median price (d)	0.01	0.08	0
USD index (d-1)	-21.82	-83.39	-3.94
VIX (d-1)	0.06*	0.21***	-0.02
Euro VIX (d-1)	-0.08	-0.33***	0.03
Constant	43.43	151.1	7.14
Number of observation	1640	870	770
R^2	0.87	0.76	0.6
Unit root test (p-value)	0	0	0
Implied threshold level		40 bps	

Notes: ***, **, * for 1%, 5%, and 10% significance level. Estimation procedure mainly follows Hansen (1997), with the only extension of using cluster-robust errors based on date. The trim rate of TAR estimation is 15%.

Table 4 Subsample robustness test

	AR(1)	TAR estimation Regime 1	TAR estimation Regime 2
$y_{d,t}$			
		$y_{d,t-1} \leq$-5.12	$y_{d,t-1} >$-5.12
$y_{d,t-1}$	0.92***	0.90***	0.80***
onshore volume (d,t)	0.12***	0.11***	0.16***
offshore tick number (d,t)	-0.50***	-0.49***	-0.53***
offshore bid/ask spread (d,t)	0.51	0.68	0.36
Deviation from CIP (d-1)	-1.07	-0.77	2.84
CNY median price (d)	0.01	0.07	0.08
USD index (d-1)	-36.71	-5.43	-335.46
VIX (d-1)	0.03	0.16**	-0.18
Euro VIX (d-1)	-0.08	-0.28**	0.01
Constant	71.79	7.47	593.80
Number of observations	1391	754	637
R^2	0.88	0.78	0.58
Unit root test (p-value)	0	0	0
Implied threshold level		32 bps	

Notes: The first and last business day is excluded from sample. ***, **, * for 1%, 5%, and 10% significance level. Estimation procedure mainly follows Hansen (1997), with the only extension of using cluster-robust errors based on date. The trim rate of TAR estimation is 15%.

Table 5 Robustness test: alternative specifications

	SETAR(1)		Stepwise regression	
	Regime 1 $y_{d,t-1} \leq$-8.71	Regime 2 $y_{d,t-1} >$-8.71	Regime 1 $y_{d,t-1} \leq -5.11$	Regime 2 $y_{d,t-1} > -5.11$
$y_{d,t-1}$	0.87***	0.90***	0.89***	0.84***
onshore volume (d,t)			0.05	0.14***
offshore tick number (d,t)			-0.30***	-0.52***
VIX (d-1)			0.19***	-0.05
Euro VIX (d-1)			-0.26***	-0.05
Constant	-1.57**	-0.49***	-0.13	2.73*
Number of observations	1640	1640	1640	1640
R^2	0.65	0.72	0.77	0.57
F-test against AR(1)	8.36		30.81	
Bootstrap p-value	0.089		0	
Implied threshold level	53 bps		32 bps	

Notes: ***, **, * for 1%, 5%, and 10% significance level. Estimation procedure mainly follows Hansen (1997), with the only extension of using cluster-robust errors based on date. The trim rate of TAR estimation is 15%. Bootstrap p-value is generated following Hansen (1999), and the bootstrap number is 10000.

Table 6 GARCH estimation

		mean regression	
$y_{d,t-1}$	0.98***	0.98***	0.97***
onshore volume (d,t)		0.05***	0.05***
offshore tick number (d,t)		-0.14**	-0.18***
offshore bid/ask spread (d,t)			-0.15
Deviation from CIP (d-1)			-0.04
CNY median price (d)			0.02
USD index (d-1)			-18.14
VIX (d-1)			0.01
Euro VIX (d-1)			-0.02
Constant	-0.10**	0.31	31.37
		variance regression	
ϵ^2_{t-1}	0.32***	0.32***	0.32***
σ^2_{t-1}	0.44***	0.42***	0.42***
onshore volume	-0.12***	-0.12***	-0.12***
offshore tick number	0.99***	1.06***	1.09***
Constant	-3.58***	-3.89***	-4.05***
Number of observation	1640	1640	1640
R^2	0.87	0.87	0.87

Notes: This table reports estimation result of extended GARCH(1,1) model, with ***, **, * for 1%, 5%, and 10% significance level. Estimation is undertaken in Eviews 8. Error distribution is assumed to be generalized error (GED).

Table 7 Quote changes per minute

		pre-announcement				post-announcement				P-value
		mean	std	skew	kurtosis	mean	std	skew	kurtosis	
Sample period	horizon	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)
Nov 2014-Jan 2015	1 min	0.06	0.5	-0.21	2.40	-0.55	2.03	-0.88	5.83	0.0027
	5 min	0.03	0.16	-0.09	2.66	-0.03	0.61	0.33	3.02	0.0024
	10 min	0.02	0.12	0.46	2.95	-0.04	0.32	0.01	2.89	0.0025
	15 min	0.01	0.10	0.81	5.72	-0.01	0.24	0.1	2.44	0.0521
March 2014- Jan 2015	1 min	-0.07	0.60	-0.76	6.1342	-0.25	2.42	-0.96	8.94	0.0015
	5 min	-0.02	0.20	-0.89	5.50	-0.05	0.68	-0.45	6.80	0.0000
	10 min	0.00	0.13	0.02	3.79	-0.03	0.36	-0.48	6.24	0.0000
	15 min	-0.01	0.11	0.04	4.34	-0.01	0.25	-0.18	4.97	0.0042

Notes: this table shows the mid-quote change per minute around the announcement of median price, within a window of 1, 5, 10, and 15 minutes. The last column is the asymptotic p-value of two-sample Kolmogorov-Smirnov test, with the null hypothesis that the sample is from the same continuous distribution. All calculations are undertaken by Matlab.

Table 8 Arbitrage around announcement

	Average return				Sharpe ratio			
Horizon	1	5	10	15	1	5	10	15
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
Strategy 1	-0.047	-0.020	-0.027	-0.020	-0.057	-0.017	-0.020	-0.013
Strategy 2	0.022	0.021	0.012	0.018	0.026	0.017	0.009	0.011
Strategy 3	-0.019	-0.003	-0.011	-0.005	-0.020	-0.002	-0.008	-0.003
Strategy 4	-0.005	0.003	-0.004	0.002	-0.005	0.002	-0.003	0.002

Notes: this table shows the rate of return of arbitrage around the announcement of median price at UTC 1:15. The horizon is 1 to 15 minutes. Financing and trade cost are assumed to be 0. Strategy 1 is first selling short of RMB, then taking long of RMB. Strategy 2 is first taking long, then selling short. Strategy 3 is following strategy 1 if USD index goes up, otherwise doing strategy 2. Strategy 4 is following strategy 2 if USD index goes up, otherwise doing strategy 1. Column (i)-(iv) shows annualized rate of return, assuming 256 business day in one year. Column (v)-(viii) shows Sharpe ratio, calculated by $\frac{E(r)}{(256Var(r))^{0.5}}$

Figure 1 data check against CNHfix

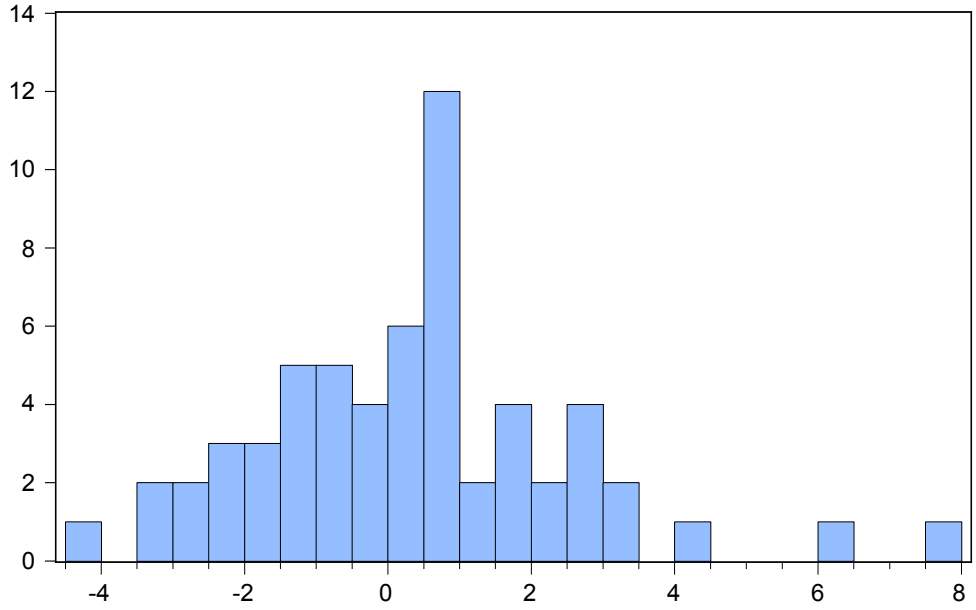
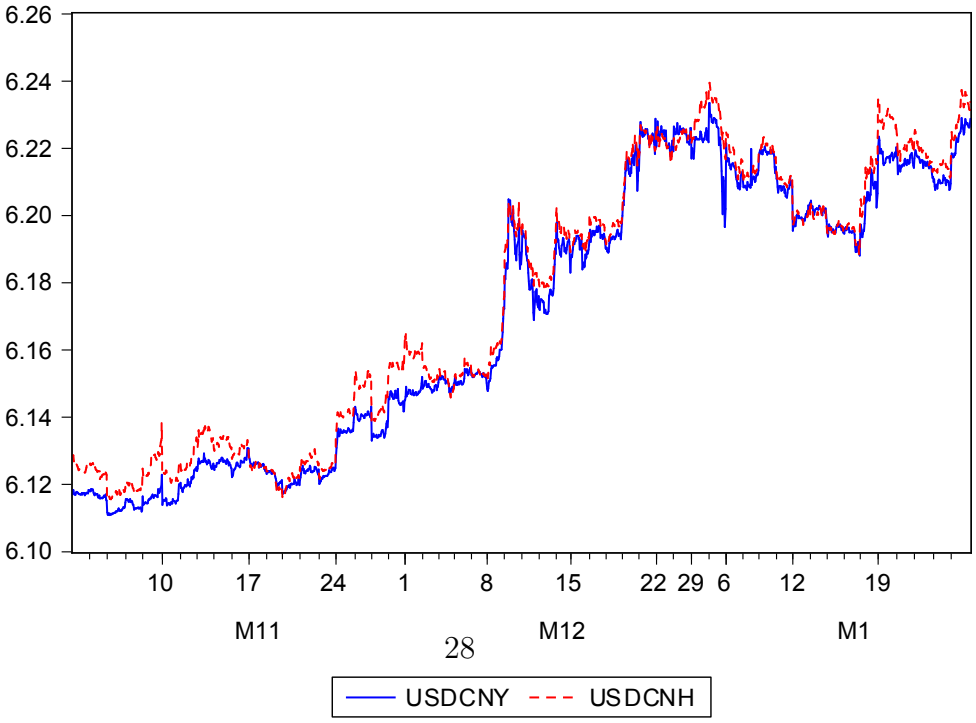


Figure 2 intraday exchange rate movement



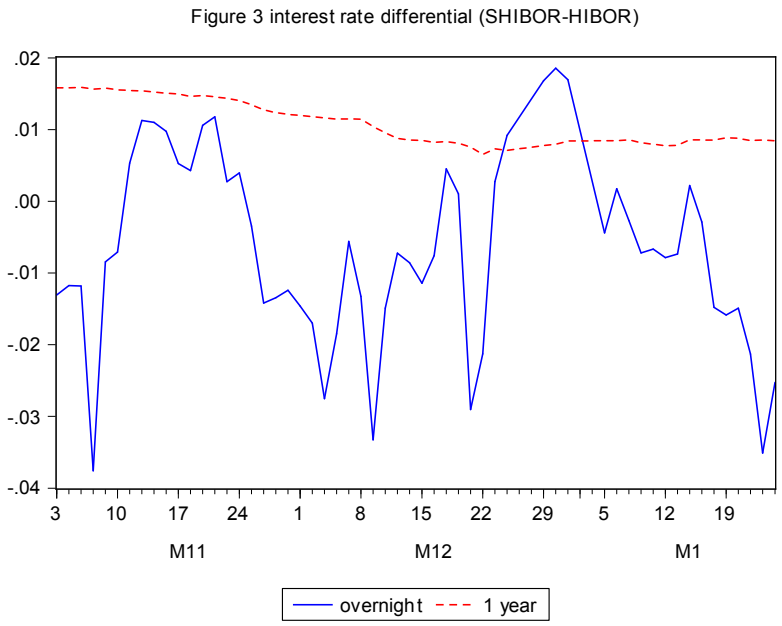


Figure 4 Test against linearity

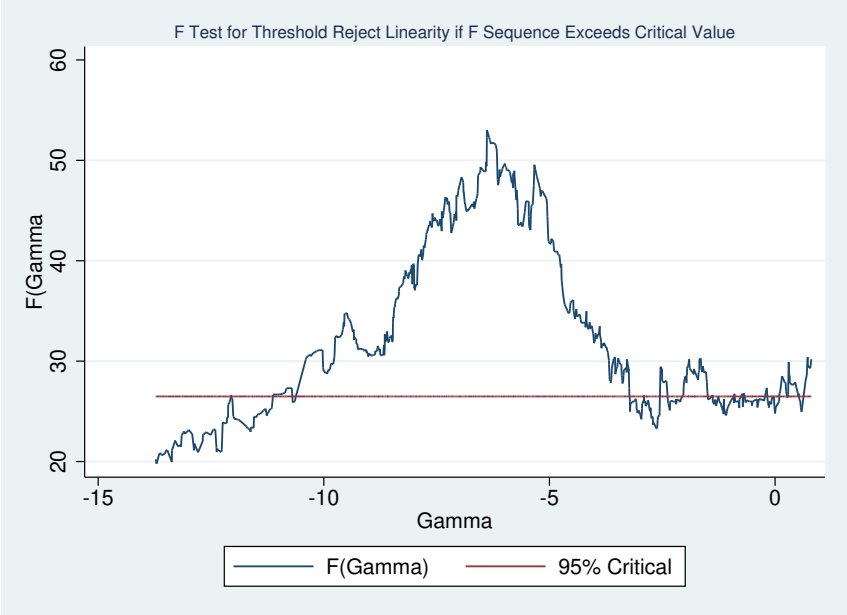


Figure 5 Threshold level estimation

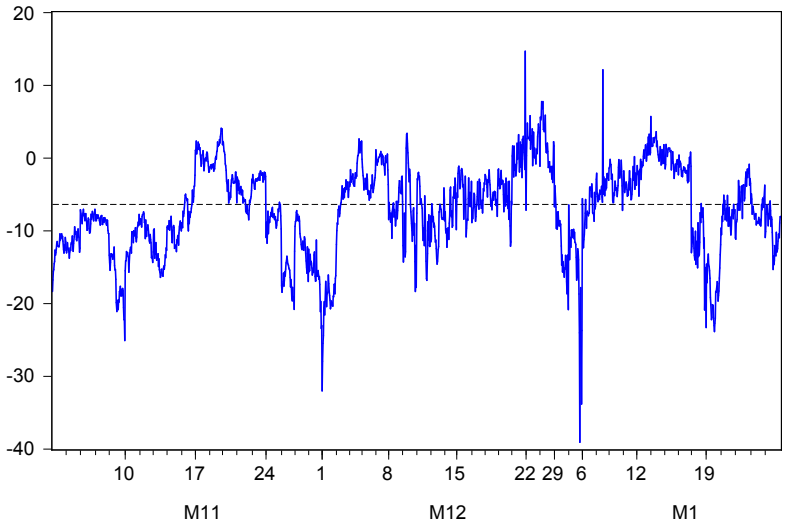
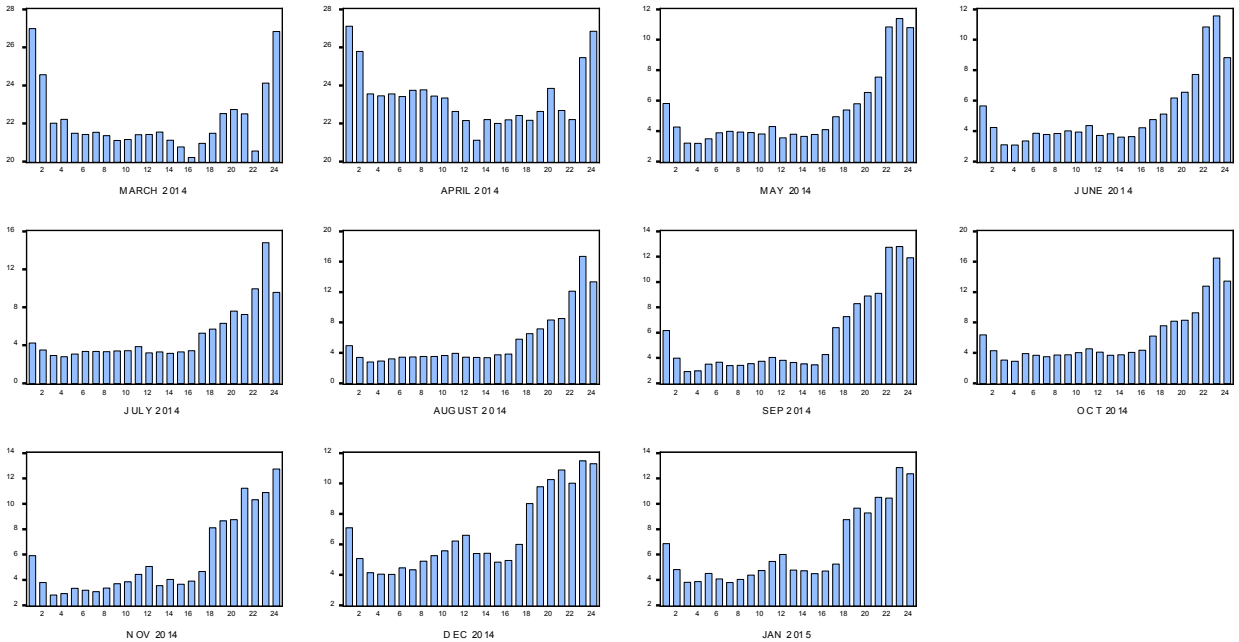
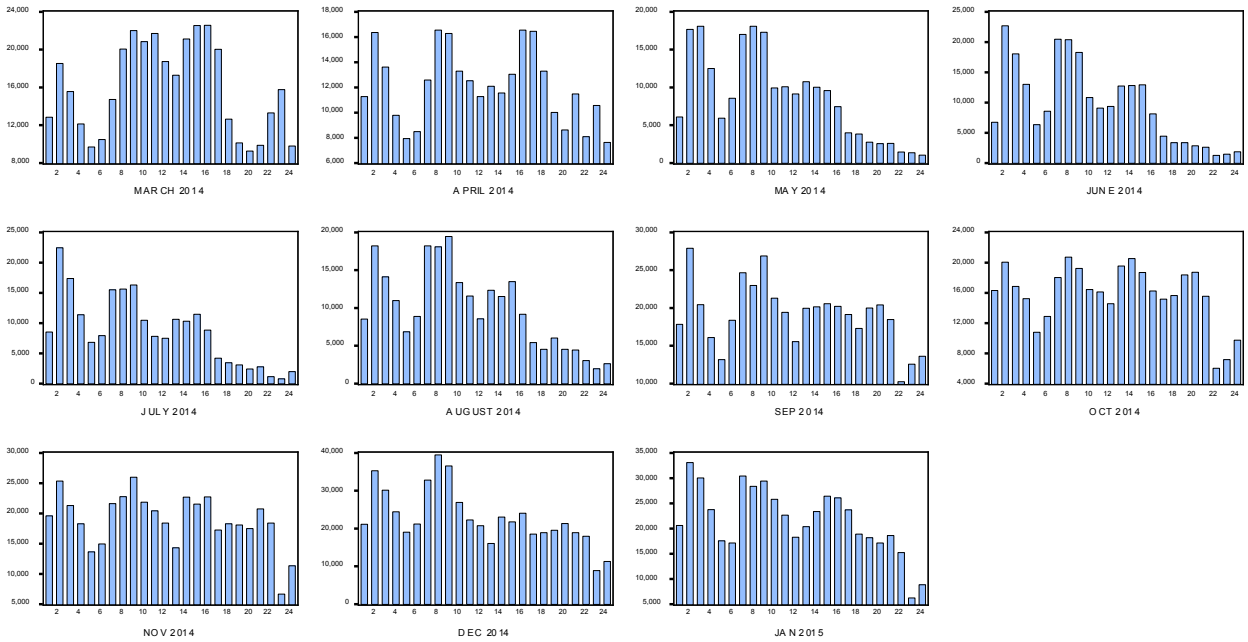


Figure 6 bid/ask spread (March 2014-Jan 2015)



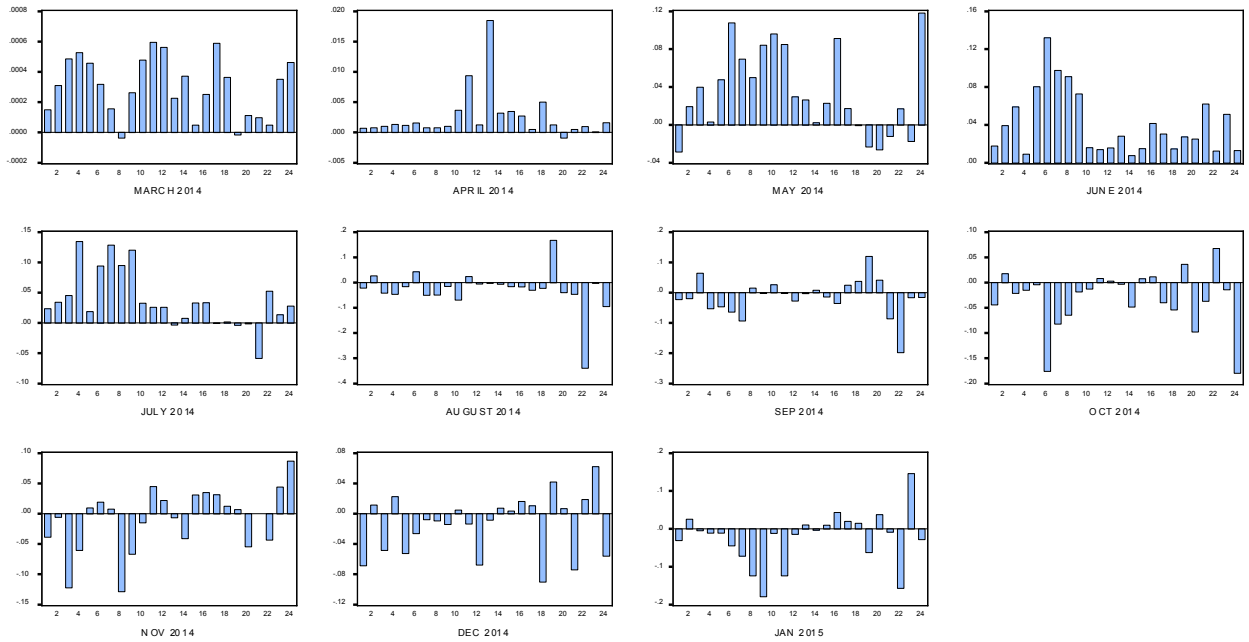
Notes: this figure shows the 24-hour bid/ask spread in CNH market from March 2014 to Jan 2015, all measured in bps.

Figure 7 tick number (March 2014-Jan 2015)



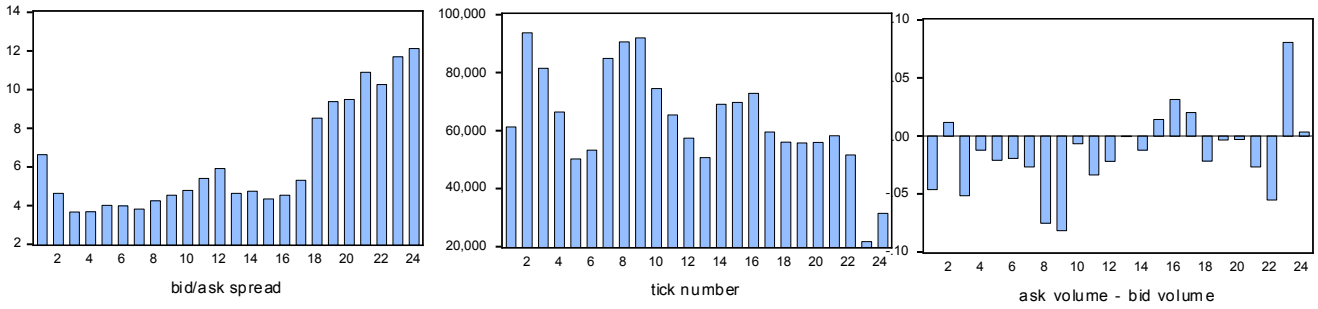
Notes: this figures shows the 24-hour tick number in CNH market, from March 2014 to Jan 2015. A tick happens whenever bid/ask price, bid volume, or ask volume is changed.

Figure 8 pseudo order flow (March 2014-Jan 2015)



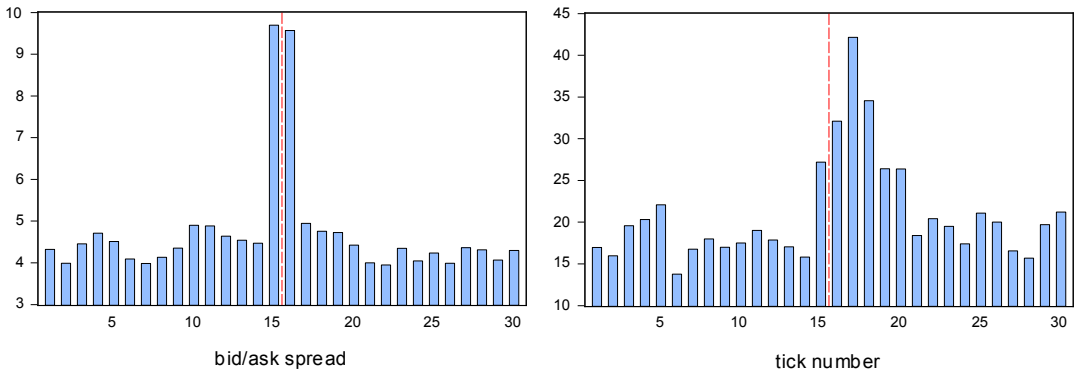
Notes: this figure shows the 24-hour pseudo order flow in CNH market from March 2014 to Jan 2015. Pseudo order flow is defined as the difference between ask volume and bid volume. A positive pseudo order flow indicates a low demand pressure.

Figure 9 sample period data (Nov 2014-Jan 2015)



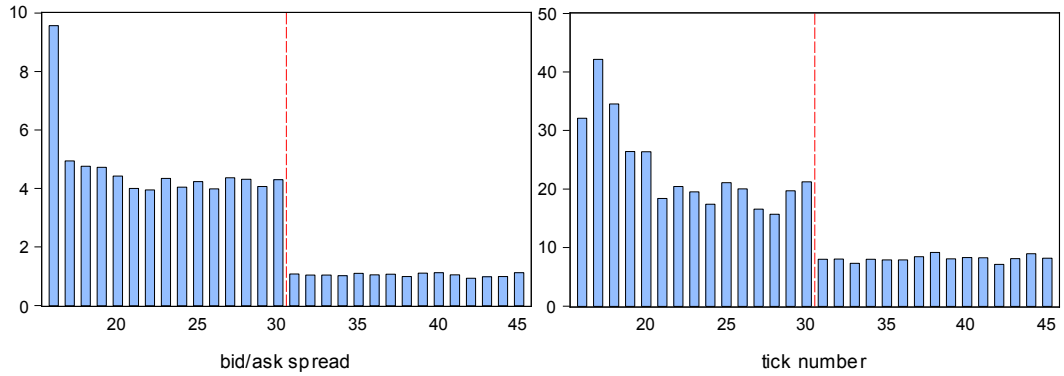
Notes: this figures shows bid/ask spread, tick number, and pseudo order flow from Nov 2014 to Jan 2015. Bid/ask spread is measured in bps, and pseudo order flow is defined as the difference between ask volume and bid volume.

Figure 10 bid/ask spread and tick number around UTC 1:15



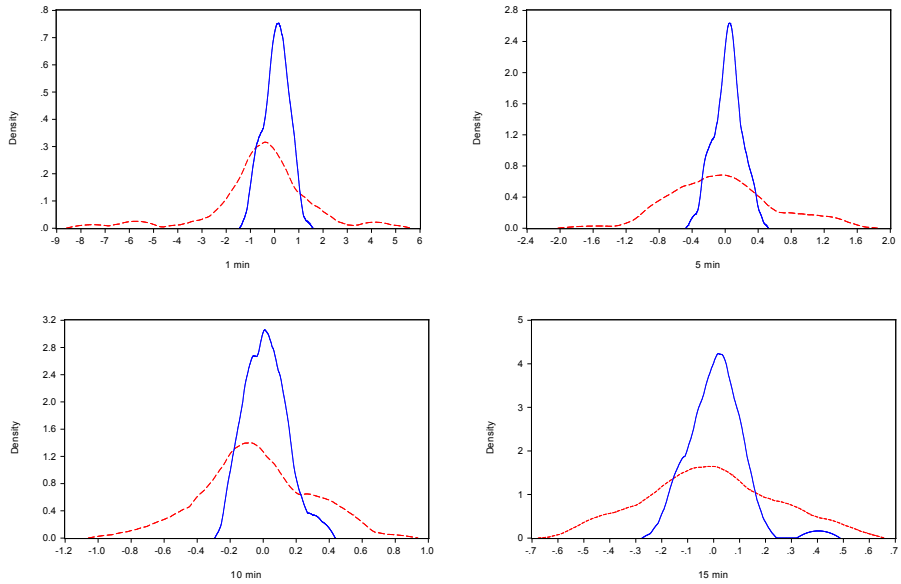
Notes: this figure shows bid/ask spread (in bps) and tick number during UTC 1:00 and UTC 1:30, sampled from Nov 2014 to Jan 2015. The red dashed line signifies UTC 1:15 when median price is announced.

Figure 11 bid/ask spread and tick number around UTC 1:30



Notes: this figure shows bid/ask spread (in bps) and tick number during UTC 1:15 and UTC 1:45, sampled from Nov 2014 to Jan 2015. The red dashed line signifies UTC 1:30 sharp when CNY market opens.

Figure 12 quote change around UTC 1:15 (Nov 2014-Jan 2015)



Notes: this figure shows the kernel density of mid-quote change around UTC 1:15, where Epanechnikov kernel is used for estimation. The quote change is defined as $(\ln S_{t+h} - \ln S_t) * 10000/h$, where h=1, 5, 10 ,15 is time horizon.

Figure 13 quote change around UTC 1:15 (March 2014-Jan 2015)

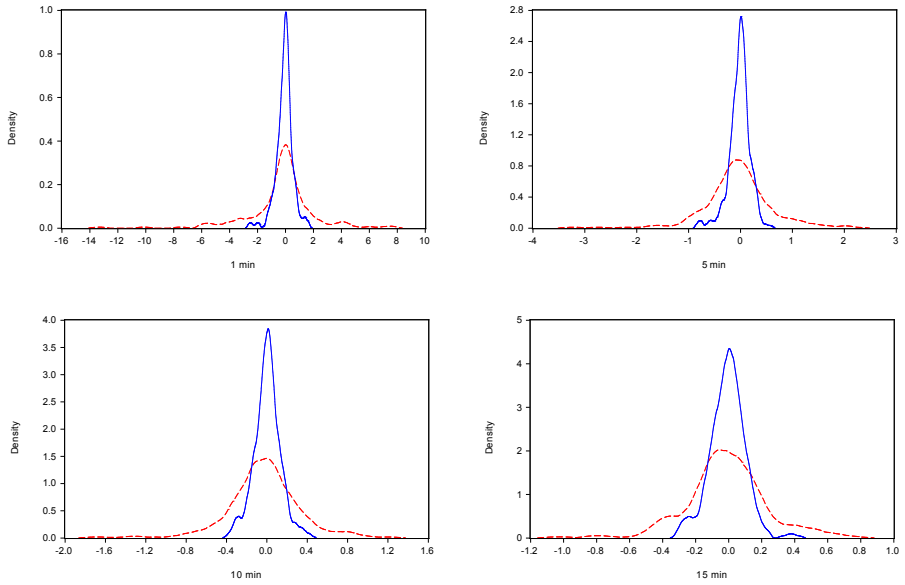
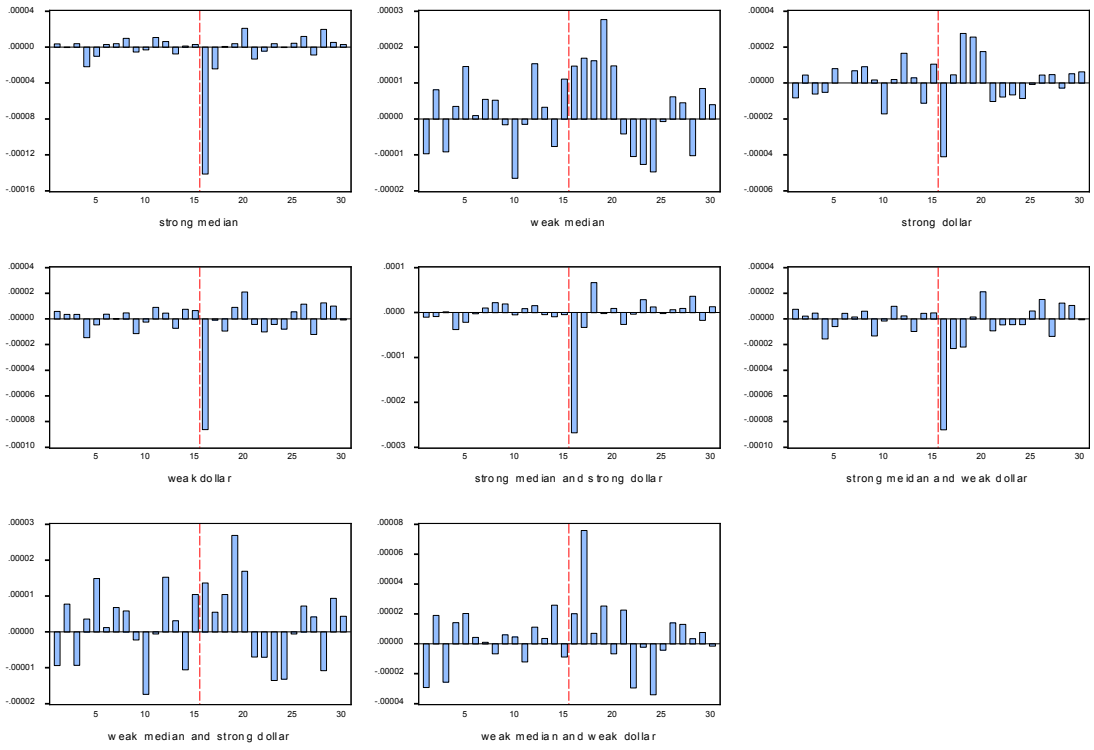


Figure 14 announcement effect of median price (Nov 2014-Jan 2015)



Notes: this figure shows mid-quote change for every minute during UTC 1:00 and UTC 1:30, and the change is defined as $\ln S_{t+1} - \ln S_t$, where S_t is the close price of mid quote for every minute. Strong median refers to sample period when the median price (RMB per USD) is decreased relative to last business day, indicating nominal appreciation of RMB. Weak median refers to sample period when the median price (RMB per USD) is increased relative to last business day, indicating nominal depreciation of RMB. Strong dollar refers to sample period when the USD index is increased relative to last business day, while weak dollar refers to sample period when USD index in decreased relative to last business day. Similarly, strong median and weak dollar refers to sample period when both median price and USD index are decreased relative to last business day.