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Microstructure and Links to the Onshore Market

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Abstract

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Keywords: Foreign Exchange Market Microstructure, Order Flow, Limit-Order Imbalance, CNH, CNY, Central Parity Rate

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1. Introduction

On the heels of China's strong economic performance that includes phenomenal economic growth, large trade surplus, and huge reserve buildup over the last decade,[1] the discussions of internationalizing the Chinese currency renminbi (RMB) have reverberated in the global community.

Indeed, there is a rapid increase in the international use of the RMB over the past few years. According to the latest triennial survey of foreign exchange turnover, the RMB was the 9th most actively traded currency in the 2013 survey while it ranked the 17th in the previous survey (Bank of International Settlements, 2013). In October 2013, the RMB surpassed the euro and Japanese yen and became the second most used currency in traditional trade finance covering letters of credit and collections, and was the number 12th payments currency of the world (SWIFT, 2013).[2] These developments are mainly contributed by expansion of offshore RMB activities. For instance, the daily average volume of inter-dealer transactions in offshore market increased by almost 9 times from 0.398 billion in 2007 to 3.903 billion in 2013.

The RMB internationalization initiative has implications for both the Chinese and the global economy. Some commentators view the initiative as a disguised component of reform efforts and an integral part of China's financial liberalization process. The experiences cumulated from offshore markets offer practical guidance to modernize the domestic financial sector. The coming of the RMB in the global financial market – similar to China's expansion into the trade arena – presents challenges to the major incumbent players including the US and its currency. It is anticipated that the geopolitical and geoeconomic landscapes will undergo substantial shifts when the RMB is becoming a full-fledged international currency.[3]

While policymakers and academics have been debating the motivations behind the policy of internationalizing RMB and its prospects, the market "created" in 2010 a second exchange rate for the RMB that is deliverable and transacted in the offshore RMB market. Indeed, market practitioners view the RMB transacted in Hong Kong as different from the RMB in China, and they coined the RMB traded in Hong Kong as CNH instead of the usual trading symbol CNY.[4]

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[1] See Song, Storesletten and Zilibotti (2011) for a model of joint determination of these three outcomes.

[2] The top 5 countries using RMB for trade finance were China, Hong Kong, Singapore, Germany and Australia. The RMB was the number 20th payments currency of the world in January 2012.

[3] See, for example, Chen and Cheung (2011), Cheung *et al.* (2011), Eichengreen (2013), and Yu (2012) for recent discussions on RMB internationalization.

[4] However, CNY is currently the only official ISO currency code used internationally (SWIFT, 2011).

In the following, we use "RMB" as a generic reference to the Chinese currency renminbi, while CNY and CNH refer to the RMB currencies transacted, respectively, onshore and offshore. Due to the effectiveness of China's capital controls, the exchange rates of the RMB in the offshore and onshore locations could be different.

Hong Kong is the home of the largest CNH center. Despite the fact that Hong Kong is physically close to China, the CNH market in Hong Kong is different from the onshore CNY market. For instance, China has capital control regulations that restrict cross-border capital flows while Hong Kong has minimum impediments to capital mobility. The effective segregation resulting from capital controls makes it possible to have two distinct exchange rates for the same currency RMB. The trading of CNY is anchored by the official daily central parity rate and trading band, while the CNH exchange rate floats freely and is determined by offshore market participants.[5]

What could be learned from the nascent CNH foreign exchange market? Potentially, the offshore market offers information on pricing the RMB currency in the absence of a trading band and capital controls. The CNH exchange rate could shed some useful insights on the (unobserved) RMB exchange rate that is driven by market forces and its fundamental determinants. There is a caveat, however. The CNH exchange rate can deviate from the unobserved market determined RMB exchange rate because the demand and supply conditions in the offshore market could be different from those of the overall RMB market. Nevertheless, the offshore market presents a good opportunity to assess the implications of market forces for the RMB exchange rate.

Against this backdrop, we study the CNH exchange rate dynamics and its potential implications for the RMB exchange rate. It is quite well known that short- and medium-run exchange rate variations are not well described by exchange rate models based on standard structural fundamentals and time-series characterizations.[6] In this study, we exploit the microstructure approach and examine the CNH exchange rate and its order flow, and their implications for the RMB.

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[5] Based on conversations with market participants and news search, there is no circumstantial evidence that the Chinese central bank has intervened in the CNH market.

[6] See, for the example, the seminal study by Meese and Rogoff (1983) and a recent confirmation by Cheung, Chinn and Pascual (2005).

The microstructure approach, pioneered by Evans and Lyons (2002), emphasizes the role of net demand pressure captured by order flow in determining exchange rates.[7] Despite there are two parties to each trade, order flow assesses demand pressure by discriminating the active trading party who initiate a trade from the passive one. Chinn and Moore (2011) show that the microstructure approach is relevant for the monthly frequency, which presumably is of more interest to central banks. Besides the CNH order flow data, the current study considers data from the limit-order book. Both types of microstructure data are from the electronic trading platform Reuters D2000-2, which is by now the main electronic inter-dealer platform for trading the CNH.

On the implications of the offshore market on the RMB, we study the causal relationships between the CNH and CNY exchange rates in full and subsample periods. In addition, we examine the implications of the officially determined RMB central parity rate for variations in CNH and CNY, and compare the ability of the onshore rate and offshore variables to predict the RMB central parity rate.

In anticipation of results, we find that, in line with existing results for other exchange rates, the CNH order flow has a strong explanatory power for the CNH exchange rate. On the interconnectedness of the offshore onshore rates, the CNH instead of the CNY on the average adjusts towards their empirical long-run relationship. However, the interaction of the two exchange rates is time-varying. Specifically, towards the end of our sample period, CNH returns an important determinant of especially short-run dynamics of the CNY, but not vice versa.

In an out-of-sample forecasting exercise we find that the return of the CNH exchange rate and the CNH order flow, but not the CNY exchange rate, have a significant predictive power for the official RMB central parity rate. The weak CNY forecast performance is unlikely to be explained by its trading band defined by the authorities. Further, the two CNH variables have non-overlapping information about the RMB central parity rate.

The next section presents the background information of the CNH market and describes the data on the CNH order flow and limit order imbalance. The main empirical exercise that covers a) the microstructure variables and the CNH exchange rate, and b) the interactions of offshore and onshore exchange rates are presented in Section 3. Section 4 reports results of some additional analyses. Some concluding remarks are given in Section 5.

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[7] See, for example, Evans (2011), King, Osler and Rime (2013) and Lyons (2001). Zhang, Chau and Zhang (2013) examine the RMB order flow data in the mainland Chinese market. The role of order flow could be restricted since the onshore trading is subject to heavy management and with limited participation of international investors.

2. The Offshore RMB Market and the CNH Order Flow

2.1 The Offshore RMB Market

Starting from 2004, Hong Kong has been China's designated testing ground of internationalizing the RMB. As recent as 2011, the policy of developing Hong Kong into a prime offshore RMB center was affirmed in China's 12th Five-Year (2011–2015). Despite competition from other offshore centers, Hong Kong has maintained its leading position and accounted for about 80% of global offshore RMB payment volumes (SWIFT, 2012).

China's choice is closely related to Hong Kong's unique economic and political status. After the sovereignty change in 1997, Hong Kong is a special administrative region of China and is allowed to maintain its own legal structure and financial system. Specifically, Hong Kong has its own currency, the Hong Kong dollar, and imposes no capital controls. The differences in the legal and financial systems make it relatively straightforward for China to institute specific rules and procedures to regulate cross-border RMB transactions with Hong Kong. Notwithstanding that Hong Kong is part of its territory, China treats Hong Kong as an offshore market in terms of cross-border RMB business.

After China allowed the RMB to move against an unspecific basket of currency in mid-2010,[8] the Hong Kong Monetary Authority and the People's Bank of China on July 19, 2010 signed the Supplementary Memorandum,[9] which is a milestone of the Hong Kong CNH market. The Memorandum literally endorses the spot CNH foreign exchange trading, among other RMB-linked products, in Hong Kong. As a result, Hong Kong has started deliverable interbank RMB foreign exchange trading, and the market has embraced the creation of the offshore CNH exchange rate, which is a "second" exchange rate of the RMB. Within a few years, the inter-bank trading in the spot CNH has grown from almost nothing to an estimated average daily volume of around $4 billion, and is dominated by transactions with cross-border counterparts.

2.2 The Data

[8] The RMB was allowed to float against an unspecific basket of currencies between mid-2005 and mid-2008. During this period, the CNY was first allowed to fluctuate within a daily band of ±0.3%. Then in May 2007, the band was widened to ±0.5%.

[9] Hong Kong Monetary Authority (2010)

We obtained the microstructure data from the Reuters D2000-2 system. Reuters is one of the leading suppliers of electronic interbank foreign exchange trading services.[10] The Reuters platform is most likely the major electronic interbank platform for CNH-trading. While the trading in the newly developed CNH market could be done via direct bilateral dealing between participants, the anecdotal evidence of other currencies suggests that trading taken place on the Reuters platform should be quite well correlated with the market-wide trading in CNH.[11] For example, the correlation between order flows across different interdealer trading platforms is 0.63 (Bjønnes *et al.*, 2011).

Our data include transaction information and bid and ask limit orders that are timed to the thousandth of a second. Following the literature, a transaction that takes place at the ask price is assigned a value of +1 and a transaction at the bid price a value of -1. The daily variable is constructed by summing these signed transactions between 00:00 and18:00 GMT, and is interpreted as a measure of net intraday buy pressure. To account for changing activity over time, we normalized this daily measure using the number of trades during the day to obtain the order flow variable used in the regression analysis. The accumulated order flow is the cumulative sum of the normalized variable.

Using the limit-order book, we constructed the limit-order imbalance variable that is given by the difference between the number of bid and offer limit orders, normalized by the trading volume. The imbalance variable measures the relative trading interest by liquidity providers and market makers. Liquidity providers are compensated by selling high (at the ask price) and buying low (at the bid price). The bid-ask spread covers the risk assumed by these traders due to the possibilities that the said transactions are not guaranteed, and they may trade against informed players. If liquidity providers have stronger trading interest in one direction, say, buying, they can post more bid limit orders than offer limit orders (Kaniel and Liu, 2006; Kozhnan *et al*., 2012).

Although the CNH-market has grown very rapidly, it is still quite small compared to, for example, the pound sterling one. For instance, during the end of our sample period, the frequency of daily CNH trade is one tenth of the sterling one. The difference in market size is

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[10] One of its main competitors is the Electronic Broking Services (EBS).

[11] Electronic trading of offshore RMB at Reuters D2000-2 was first under the Reuters code (RIC) CNY=D2 until March 18 2011, and after that as code CNH=D2.

also reflected in market liquidity, for which the relative bid-ask spread in the CNH-market is about 4 times wider than the very low 1.5 basis point of the sterling.[12]

The evolution of the CNH exchange rate is plotted in Figure 1. For comparison purposes, we imposed the CNY exchange rate and the RMB central parity rate in the same Figure. All the rates are per US dollar exchange rates. Due to the availability of data on CNH and its order flow, we study the sample period from September 27, 2010 to August 27, 2013. In passing, we note that the central parity rate (which is commonly referred to as the 'fixing rate') is posted by the China Foreign Exchange Trade System in the morning of every business day.[13] The central parity is used to define the band within which the CNY exchange rate is allowed to fluctuate. On April 14, 2012, indicated by the vertical line in Figure 1, the People's Bank of China widened the daily trading band around the daily central parity rate from ±0.5% to ±1 %.[14]

A few observations are in order. First, since the resumption of the 'managed floating exchange regime' on June 19, 2010 (People's Bank of China, 2010), the value of the RMB fixing rate has steadily appreciated, and its movement resembles an upward crawl against the dollar (Ma and McCauley, 2011). During the sample period, RMB appreciated by more than 8% against the US dollar.

Second, the variability of the CNY exchange rate is noticeably larger after the widening of its trading band on April 2012. Third, the CNH exchange rate is more volatile than the CNY rate, and the central parity rate. Specifically, during the sample period, the standard deviations of annualized percentage returns are, respectively, 44.44, 26.25 and 21.75 for CNH, CNY and the fixing rate. Relatively speaking, the volatility of these Chinese exchange rates is low compared to the standard deviation of 158 for the pound sterling, which is a more typical floating currency.

Fourth, while the CNH and CNY exchange rates usually track each other quite well, there are episodes in which they display a large disparity. For instance, the CNH had a large premium over CNY in the third quarter of 2010. The premium is usually attributed to a liquidity squeeze due to a stronger-than-expected demand for CNH for cross-border trade settlement. The

[12] The information is obtained from the Reuters D2000-2 system.

[13] In addition to the US dollar, the fixing rates of eight other currencies; namely, euro, Japanese yen, Hong Kong dollar, British pound, Australian dollar, Canadian dollar, Malaysian ringgit, and Russian ruble are available. These fixed rate postings are authorized by the People's Bank of China. The US dollar central parity rate of RMB is based on a trimmed weighted average of prices from all liquidity providers obtained by the China Foreign Exchange Trade System before the opening of the market each business day. The weights are set discretionally, but linked to the size of a liquidity provider's business performance. See http://www.chinamoney.com.cn/fe/Channel/2781516.

[14] On March 15, 2014, the People's Bank of China widened the daily trading band to ±2 %.

premium subsided when the Hong Kong Monetary Authority activated its CNH liquidity provision through the swap arrangement with the People's Bank of China.

Fifth, the CNH suffered its largest discount to CNY in September 2011. The sell-off of CNH was associated with the surge in the global market risk that led to unwinding of emerging market currencies including the CNH.

Figure 2 graphs the CNH exchange rate and its accumulated order flow. With the exception of the late third quarter and the fourth quarter of 2011, the order flow and CNH exchange appear to move in tandem. The formal statistical analysis of these two variables is presented in the next Section.

3. Empirical analysis

In the following subsections, we study the links of the CNH exchange rate to a) its order flow, and b) its onshore counterpart.

3.1 CNH and Order Flow

Evans and Lyons (2002) present a model based on portfolio adjustment to illustrate the role of order flow in determining an exchange rate. The net market demand effect captured by order flow in the current context could be examined using the regression

$$\Delta H_t = \alpha + \beta \Delta X_t + \gamma \Delta F_t + \varepsilon_t, \qquad (1)$$

where ΔH_t is the return of the CNH exchange rate measured by its first log difference, ΔX_t is the CNH order flow, F_t is the three-month CNH and US dollar interest rate differential that represents effects of fundamentals, and ε_t is the regression error term. The definitions and sources of these and other variables used in the study are listed in the Appendix.

The results of estimating (1) are presented in Table 1. The lagged CNH return is added to control for possible serial dependence. It turns out that the lagged return is insignificant in all cases considered. The result under column (1) shows that the interest rate differential exhibits no substantial explanatory power.

As CNH is among the group of emerging market currencies that are heavily affected by the market attitude toward risk – the so called risk-on and risk-off phenomenon – we include the change of the logarithm of the J.P. Morgan currency volatility index of emerging markets in the specification under column 2.[15] The volatility index gauges the market's fear about the currencies of emerging countries, and accounts for about 7% of CNH variations on the margin. A high level of risk drives capital away from these emerging market currencies and, as a sympathy effect, away from CNH holdings.

The order flow variable that represents the net market pressure has the expected positive and significant effect. During the sample period, as graphed in Figure 2, the negative order flow indicating active buying of the Chinese currency moves down the value of the US dollar against the CNH. The marginal increase in the adjusted R-squares estimate is quite large – from 8% under column (2) to 20% under column (3). The finding attests the relevance of order flow in explaining the variability of the CNH exchange rate.

Indeed, when similar data were used and controlled for the different levels of exchange rate volatility, the impact of CNH order flow in Table 1 is similar to, say, the pound sterling order follow on the pound sterling exchange rate. Specifically, a one standard deviation change in order flow accounts for about half of a one standard deviation change in the exchange rates, which is sizable in an economic sense.

The limit-order imbalance variable has a significant and positive impact on the CNH exchange rate. While impatient informed traders place market orders, informed traders with long-lived information are likely to use limit-orders to secure better prices at the expense of execution uncertainty (Kaniel and Liu, 2006). In the current study, an increase of the imbalance by construction is indicative of the potential demand for the US dollar. Even though the coefficient estimate is small in magnitude, and its marginal explanatory power is small, its quality effect is in line with the interpretation (Kozhnan *et al*., 2012).

In sum these results echo the extant evidence on effects of microstructure variables on exchange rate dynamics. The explanatory power of the specifications that incorporate order flow and order imbalance is quite high for high frequency exchange rate data.[16]

There is a caveat, however. The contemporaneous relationship between CNH returns and order flow data presented in Table 1 could be driven by the effect of CNH on order flow – a high CNH exchange rate return attracts money flow into the currency. Another concern is that the

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[15] The results are robust to some alternative risk measures including the G7 FX volatility, the CSFB Risk aversion index, the VIX index, and illiquidity risk measured by bid-ask spreads. For instance, the VIX does not offer any exceptional explanatory power. All results are available upon request.

[16] In passing, we note that the order flow effect is highly significant over different subsamples as well. Results are available upon request.

first-difference specification may undermine the long-term linkage between CNH and its accumulated order flow.

The cointegration framework offers an alternative setting to investigate the role of microstructure variables. Specifically, we follow the literature and consider the trivariate system (H_t, X_t, F_t). The unit root test results indicate that each of these data series is a I(1) process. Mixed cointegration test results were obtained from the Johansen test and Phillips-Ouliaris test (Johansen, 1991, Phillips and Ouliaris, 1990). While the former test failed to reject the null hypothesis of no cointegration, the latter test rejected the no-cointegration null. The results from estimating the vector autoregression correction model (VECM), however, lend support to the inference that the three variables have one cointegration relationship.[17] Thus, we proceed with specification that allows for one cointegration relationship, and report in Table 2 the results of estimating the VECM:

$$\Delta H_t = \alpha_1 + \delta_1 EC_{t-1} + \phi_1 \Delta H_{t-1} + \beta_1 \Delta X_{t-1} + \gamma_1 \Delta F_{t-1} + \varepsilon_{1t}, \tag{2}$$

$$\Delta X_t = \alpha_2 + \delta_2 EC_{t-1} + \phi_2 \Delta H_{t-1} + \beta_2 \Delta X_{t-1} + \gamma_2 \Delta F_{t-1} + \varepsilon_{2t}, \tag{3}$$

and

$$\Delta F_t = \alpha_3 + \delta_3 EC_{t-1} + \phi_3 \Delta H_{t-1} + \beta_3 \Delta X_{t-1} + \gamma_3 \Delta F_{t-1} + \varepsilon_{3t}, \tag{4}$$

where EC_{t-1} is the error correction term[18], and the lag structure is selected using the information criteria AIC and SC.

The VECM results show that the order flow affects the CNH exchange rate through two channels. One is the empirical long-run channel represented by equilibrium correction via the error correction term. The other one is the short-term channel captured by the lagged order flow. The EC_{t-1} and ΔX_{t-1} effects on CNH exchange rate returns have their expected signs and are statistically significant. The finding reinforces the order flow effect reported earlier, and is supportive of the notion that order flow causes CNH returns.

The order flow appears exogenous to these variables. None of the coefficient estimates under the ΔX_t specification is statistically significant. On the other hand, the interest rate differential responds to the error correction term with the expected sign – a positive deviation

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[17] For brevity, the unit root and cointegration test results are not reported, but available from the authors. Note that, according to the Granger-Engle representation theorem (Engle and Granger, 1987), the significant equilibrium correction in the VECM is indicative of a cointegrated system.

[18] The error correction term, with the trend and constant included, is given by H_t -.0012 X_t +.0108 F_t, and the t-statistics of the two coefficient estimates are, respectively, -1.85 and 2.87.

from the empirical long run relationship leads to a decrease in the differential which in turn will shrink the error correction term, *ceteris paribus*.

Despite the error correction specification reveals the long-term and short-term impacts of order flow on the return of CNH exchange rates, the explanatory power as given by the estimate of the adjusted R-squares is quite small. To explore the roles of other possible determinants, we study an augmented version of equation (2):

$$\Delta H_t = \alpha_1 + \delta_1 EC_{t-1} + \phi_1 \Delta H_{t-1} + \beta_1 \Delta X_{t-1} + \gamma_1 \Delta F_{t-1} + \partial Z_t + \varepsilon_{1t}, \qquad (5)$$

where the augmented variable Z_t includes currency volatility index, contemporaneous and lagged) limit order imbalances, and contemporaneous order flow. The results of estimating (5) are presented in Table 3.

For comparison purposes, Column (1) repeats the results of the ΔH_t equation from Table 2. Similar to the results in Table 1, the inclusion of the emerging market currency volatility variable improves the adjusted R-squares estimate by about 7% (Column 2). The effect of the limited order imbalance variable appears to come through the contemporaneous channel – the effect of the lagged variable becomes statistically insignificant in the presence of the contemporaneous limited order imbalance. The order flow variable, on the other hand, exerts both contemporaneous and lagged effects on the return of CNH. The lagged effects from order flow can be interpreted as slow learning or over-reaction (e.g. due to illiquidity). The positive sign reported for all cases considered in the Table lends support to the slow learning or partial adjustment mechanism. The lagged order flow effect, as expected, is weaker than the contemporaneous effect.

In the presence of these additional microstructure variables, the error correction term loses its statistical significance and the other three lagged variables under the VECM specification retain or reinforce their levels of significance. Put all these together, we infer that the order flow equilibrium correction effect on CNH returns in Table 2 is spurious. The order flow effect is likely to work through the short term channel and transmitted via the contemporaneous and lagged order flow variations.

Among the ΔH_t specifications in these three Tables, the specification that incorporates both current and lagged order flow variables yields the largest estimate of adjusted R-squares. The results reinforce the role of flow order in explaining CNH exchange rate movements.

3.2 Offshore and Onshore Interactions

The CNH and CNY exchange rates are exchange rates of the same currency RMB. What is the linkage between these two exchange rates? China's capital control policies segregate the supply and demand conditions in two markets of these two exchange rates, and keep them separated. Even though they are the prices of the same RMB, they could move separately. However, there are reasons to believe that the CNH exchange rate could affect the CNY exchange rate, and vice versa.

The launch of the offshore RMB market in general and the CNH foreign exchange trading in particular are hailed as notable events in China's process to liberalize its financial sector. In principle the CNH foreign exchange market helps China to gauge the implications for liberalizing the RMB exchange rate. In the absence of tight and direct capital controls, the CNH foreign exchange market attracts participants from different parts of the world and allows market forces to influence the CNH exchange rate. Thus, price discovery is believed to be a key function of the CNH exchange rate.

The practical question is: Does the information revealed by the CNH exchange rate transmit to the CNY exchange rate? Despite the rapid growth of the nascent CNH foreign exchange market, it is still small compared with the on-shore RMB market.[19] More importantly, the CNY exchange rate is anchored to the daily officially determined RMB fixing rate and is only allowed to fluctuate within a defined band around the fixing rate. Even though China does not directly control the CNH rate, she could indirectly influence it through the RMB fixing and other policy measures. The CNH movement may thus take the hints from the CNY exchange rate.

To shed some insight on the interaction of onshore and offshore RMB markets, we study the causal relationship of the CNY and CNH exchange rates. Since the standard unit root tests affirmed that both exchange rate series are I(1) process, the cointegration approach that allows for long-run interaction is adopted to investigate the their dynamics.[20]

Both the Johansen test and Phillips-Ouliaris test rejected the no-cointegration null and suggested the presence of one cointegration vector in the bivariate system of CNY and CNH

[19] According to the 2013 BIS triennial survey, the onshore market accounted for 59% of the total global RMB trading.

[20] For completeness, we estimated the bivariate (ΔY_t, ΔH_t) vector autoregression specification. For the sample under consideration, there is no cross-exchange rate interaction. The results are available upon request.

exchange rates.[21] The estimated cointegrating vector is (1, -1.0735) and the estimate is highly significant with a t-statistic of -27.78. Thus, the error correction term used in the corresponding bivariate VECM specification is (Y_t - 1.0735H_t), where Y_t is the CNY exchange rate. In passing, it is noted that the estimated cointegrating vector is quite close to (1, -1); indicating that the two exchange rates tend to move in tandem on average despite some large deviations observed in Figure 1.

Table 4 presents the results of estimating the bivariate (Y_t, H_t) VECM specification:

$$\Delta H_t = \alpha_1 + \delta_1 EC_{t-1} + \phi_{11}\Delta H_{t-1} + \phi_{12}\Delta H_{t-2} + \beta_{11}\Delta Y_{t-1} + \beta_{12}\Delta Y_{t-2} + \varepsilon_{1t}, \quad (6)$$

and

$$\Delta Y_t = \alpha_2 + \delta_2 EC_{t-1} + \phi_{21}\Delta H_{t-1} + \phi_{22}\Delta H_{t-2} + \beta_{21}\Delta Y_{t-1} + \beta_{22}\Delta Y_{t-2} + \varepsilon_{2t,} \quad (7)$$

where the lag structure is determined by information criteria. Recall the error correction term EC_{t-1} is given by (Y_{t-1} - 1.0735H_{t-1}).

The CNY and CNH exchange rates display different equilibrium correction mechanisms – the former exchange rate is not statistically affected by the error correction term while the latter is statistically affected. The estimates of individual coefficients of lagged returns indicate that there are some significant cross exchange rate effects. The second lagged CNH return has a marginal positive impact on the CNY return. A similarly cross-rate lagged effect is observed from CHY return on CNH. Nonetheless, the usual Granger causality block exogeneity Wald test indicated the absence of causal relationship between ΔH_t and ΔY_t. Overall, the VECM results indicate that the equilibrium adjustment is mainly borne by the CNH exchange rate and the short-term feedback between the two RMB exchange rates is not very strong.

Similar to the results in Table 2, the explanatory power of the bivariate VECM(Y_t, H_t) specification is quite low. Again, the roles of other possible determinants are investigated using the following augmented specifications:

$$\Delta H_t = \alpha_1 + \delta_1 EC_{t-1} + \phi_{11}\Delta H_{t-1} + \phi_{12}\Delta H_{t-2} + \beta_{11}\Delta Y_{t-1} + \beta_{12}\Delta Y_{t-2} + \partial_1 Z_t + \varepsilon_{1t}, \quad (6)$$

and

$$\Delta Y_t = \alpha_2 + \delta_2 EC_{t-1} + \phi_{21}\Delta H_{t-1} + \phi_{22}\Delta H_{t-2} + \beta_{21}\Delta Y_{t-1} + \beta_{22}\Delta Y_{t-2} + \partial_2 Z_t + \varepsilon_{2t,} \quad (7)$$

[21] For brevity, the unit root and cointegration test results are not reported, but available from the authors. Craig *et al.* (2013) Funke *et al.* (2014) and Maziad and Kang (2012), for example, studied CNH and CNY interactions using threshold autoregressive models or GARCH models, which do not explicitly allow for long-term interactions.

where Z_t include the extra explanatory variables. In addition to the microstructure and macroeconomic variables, we examine the impacts of the official RMB central parity rate on the CNH and CNY exchange rate dynamics. Specifically, we consider a) the change in the log of the central parity rate, ΔP_t, and b) the deviations from the central parity rate, $(P_t - H_{t-1})$ and $(P_t - Y_{t-1})$. The time subscripts used to construct the deviation variables is due to the fact that the central parity rate is announced before the trading in the morning and the CNH and CNY rates are end-of-the-day quotes. That is, the deviation variables capture the information reached the market between yesterday's closing and today's opening.

The results of estimating (6) and (7) are presented in Table 5. To facilitate discussions, we repeated the generic VECM results under Column (1). The basic VECM results are qualitatively the same in the presence of these additional variables. Specifically, it is the CNH return and not the CNY return variable that reacts to the error correction term. The cross-rate effects are similar to those revealed under the bivariate VECM(Y_t, H_t) setting.

The additional variables have differential abilities to explain variations in returns on CNY and CNH. The marginal explanatory power of the emerging market currency volatility variable, for instance, is again about 7% for the return on CNH but is only about 1% for the CNY return. The limited effect on the CNY reflects this exchange rate is less subject to market influences. The interest rate differential again has no significant impact on either exchange rate.

Apparently, the CNH order flow affects both CNH and CNY exchange rates. The effect on returns on CNH is qualitative similar to the one revealed in Table 4 – both the lagged and contemporaneous order flow variables are significant and have contributed a noticeable improvement in the model performance. For the CNY exchange rate, only the contemporaneous CNH order flow is statistically significant and its presence increases the estimate of adjusted R-squares by only 1%.

The CNH limited order imbalance displays a relatively weak explanatory power. It does not have a significant impact on CNY exchange rates and, in the CNH case, yields a marginal increase of 1% in the adjusted R-squares.

Thus, among the two CNH related microstructure variables, it is the order flow that has implications for the CNY exchange rate. Because the two markets are separated by China's capital control policies, the impact of these microstructure variables is stronger on the CNH than on the CNY.

The official RMB central parity rate has substantial influences on both the CNH and CNY even though its effects work through different variables. In the case of CNY, the exchange rate return responds quite strongly to the change in the central parity rate. At the risk of repetition, we note that the central parity rate is announcement before the morning trading session and the exchange rate return is based on end-of-the-day quotes. Our estimates suggest that, over the average, the change in the central parity rate accounts for slightly more than one half of the change in the CNY exchange rate. The inclusion of the change in central parity rate leads to a big jump in the estimate of the adjusted R-squares – from 6% under Column (7) to 28% under Column (8). The deviation from the central parity rate also affects the CNY but to a smaller extent – the improvement in the estimate of the adjusted R-squares is about 1%.

The CNH exchange rate, on the other hand, appears to be better explained by its deviation from the central parity rate than the change in the central parity rate. The change in the central parity rate yields a 2% increase while the deviation from the central parity rate yields an additional 11% in the estimate of the adjusted R-squares. The response pattern is different from that of the CNY exchange rate. One possible reason is that the CNH is not subject to the trading band imposed on CNY and, the extra degree of freedom allows the CNH exchange rate to anticipate and respond to the future RMB exchange rate movement. The deviation from the central parity rate thus contains information about refinement of adjustment to the official rate.

The performance of the augmented models is quite encouraging. For daily exchange rate data, the model explains up to 29% of the variability of CNY returns and 39% of CNH return movements. The difference in the explanatory power apparently is due to the effectiveness of the CNH microstructure variables in describing the variations of these two exchange rates.

4. Additional Analyses

4.1 Time-Varying Relationship

As discussed in the beginning of the previous section, there are reasons for the CNH exchange rate to affect the CNY one, and vice versa. The results based on the whole sample period tend to support the notion of, on the average, CNY is affecting CNH. It is quite possible that the causal link is not constant and changes over time. The market participant’s currency choice could depend on the relative strength of the two RMB exchange rates. For instance, if the

CNH is stronger than CNY, Chinese importers will find it benefits to use CNH to settle their US dollar obligations. Under turbulent market conditions that trigger risk-off trades, the action is likely to take place first in the CNH, instead of the CNY, foreign exchange market.

To explore these possibilities, we examine the causal relationship between CNY and CNH exchange rates in three subsample periods. These subsamples are: (i) the beginning of the sample period to September 21, 2011, (ii) September 22, 2011 to April 13, 2012; and (iii) April 14, 2012 to the end of our sample period. September 21, 2011 is chosen as a breaking point because it is the beginning of a quite turbulent period in which the CNH displayed an unusually large discount to the CNY. April 14, 2012 is the date that the official CNY trading band was widened from ±0.5% around the central parity rate to ±1%. While these choices may appear somewhat arbitrary, the results shed some light on the variability of the interconnectedness of the two exchange rates. Table 6A presents the results of estimating the bivariate VECM(Y_t, H_t), and Table 6B reports the short-run Granger causality test results.

In all three subsamples the CNH exchange rate displays the strongest attraction to the empirical long-run equilibrium term. The lagged error correction term is significant in the three ΔH equations; indicating that the CNH exchange rate is responding to the deviation from the empirical long-run relationship. For the ΔY equations, the error correction term is only statistically significant in the second subsample, which includes a period inflicted by hectic market conditions.

The cross-exchange-rate effect varies across these three subsamples. The estimates of the coefficients of lagged ΔH's and ΔY's indicates that a) lagged ΔY's tend to affect the CNH exchange rate though the effect seems weakened a bit in the third subsample period, and b) the CNY exchange rate is affected by lagged ΔH's only in the third subsample period.

The causal relationship between these two return series is formally tested, and the results are presented in Table 6B. The causality test results are in line with observations based on coefficient estimates. Specifically, in the early periods, the causality runs from the change in the CNY exchange rate to the CNH exchange rate. Towards the end of our sample period, the empirical causal relationship runs from the CNH foreign exchange market to the CNY market. Recall that the CNY has a widened trading band in the last subsample period – the increased degree of flexibility could allow CNY to respond better to variations in CNH. While the causality test gives information on the relative timing of events and, not necessary, a measure of economic causality, the test results are suggestive of the way how the two markets respond to each other over these subsample periods.

Given the apparent arbitrariness of the choices of these subsamples, we consider the rolling "regression" analysis to shed further insight on the causality pattern. Figure 3 plots the error correction coefficient estimates together with their t-statistics from the rolling estimation of the bivariate VECM(Y_t, H_t). The rolling sample size is 200 daily observations.

The rolling regression results affirm the result of the pattern of equilibrium corrections of the CNY and CNH exchange rates tend to vary over time (Figure 3). Besides time variability, the error correction term is positive and mostly statistically significant for the CNH specification and significantly negative only a few times for CNY. The findings are largely in accordance with the subsample results in Table 6A.

The *p*-values of the block exogeneity test of causality are graphed in Figure 4. Again, the time variations in the causation feedback between the returns on the two exchange rates are quite apparent. The causal effect of ΔY on ΔH appears stronger in the early sample period than the later part, and the ΔH's influence on ΔY is more prominent in 2013 than other years. Specially, the lagged ΔYs displayed significant impacts on CNH variations during the late 2011 and the first half of 2012, while the significant effect of lagged ΔHs showed up in the 2013 subsample.

In sum, the rolling regression analysis reinforces the subsample exercise; even though the CNY has, on the average, a net effect on CNH, we should not overlook the changes in the lead and lag relationship between these two exchange rates of the RMB. The CNH exchange rate is exhibiting stronger short-term causal effect over time.

4.2 Forecasting Performance

Another way to compare the onshore and offshore variables is to compare the abilities of the CNY and CNH exchange rates, and the CNH order flow variable to forecast the official RMB exchange rate. Specifically, we generate the one-step ahead forecasts from a rolling regression with 200 observations

$$\Delta P_t = \alpha + \beta W_{t-1} + \varepsilon_t, \qquad (8)$$

where ΔP is the change in the RMB central parity rate, and the predictor W_{t-1} can be either (i) the return on the CNH exchange rate, ΔH_{t-1}, (ii) the return on the CNY exchange rate, ΔY_{t-1}, or (iii) the CNH order flow, ΔX_{t-1}. The out-of-sample forecast performance of the three predictors, relative to that of a random walk with a drift is presented in Table 7. As a pure random walk without drift yielded a worse forecast performance and, thus, is not discussed for brevity.[22]

The out-of-sample forecast performance of the onshore exchange rate ΔY is worse than the offshore market variables, ΔH and ΔX. As a predictor, ΔY yields the largest root mean squared prediction error (RMSE) and mean absolute prediction error (MAE) among these three predictors. The order flow variable gives the smallest forecast error measures. The Diebold-Mariano test, indeed, shows that the forecast performance of the two offshore variables is significantly better than the random walk with drift specification. The results attest the relevance of the information content of these offshore variables on the official RMB exchange rate represented by its official central parity rate.

Why does the offshore RMB rate out-forecast the onshore rate? One possible reason is that the fluctuation of the latter rate is constrained by its daily trading band while the latter rate is not. To evaluate such a possibility, we construct the location variable (Z_t - P_t), where Z_t is either Y_t (CNY) or H_t (CNH). The variable is then normalized by the trading band prevailing at time t. If the CNY forecast ability is restrained by the trading band, its forecast error is likely to be associated with the normalized location variable.

For the forecast exercise involved CNY, the sample correlation coefficients of the lagged squared location variable and squared estimated forecast and the absolute variables are, respectively, 0.20 and 0.19. These two sample correlation coefficients are neither statistically significant nor statistically larger than the corresponding ones (0.14 and 0.03) of the CNH case. We also considered subsamples of the normalized location variable and estimated forecast error based on the quantiles of the former variable. Again, there is no sign that the estimated forecast error is correlated with the normalized location variable that is close to the trading band limits. Apparently, the relatively inferior performance of CNY is not attributed to the presence of the trading band.

Another observation is that both CNH and its order flow predict the RMB central parity rate. Is the forecast performance of observable CNH derived from the not publicly observable order flow that measures the market pressure, or vice versa? To evaluate their relative performance, we consider the regression

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[22] The forecast exercise based on a rolling sample of 100 observations gave qualitatively similar results, which are available upon request.

$$\Delta P_t = \alpha + \beta_1 \Delta H_{t-1} + \beta_2 \Delta X_{t-1} + \varepsilon_t, \quad (9)$$

that includes both the lagged return on CNH and the lagged order flow. In the full sample, both β_1 and β_2 estimates (0.0869 and 0.0002) are statistically significant with robust t-statistics of 2.76 and 2.23, respectively. Their time varying behaviors are illustrated from rolling regression results (Figures 5 and 6). For both variables, the coefficient estimates tend to be larger in the later sample period. Their levels of significance also vary over time. In sum, the evidence indicates that the effects of the two offshore variables a) do not completely overlap with each other, b) vary over time, and c) diverge towards the end of sample period in the sense that the order flow variable becomes less significant over time while the CNH return maintains its relatively high level of significance. That is, the two offshore variables have their own unique information contents about the RMB central parity rate.

5. Concluding Remarks

During the process of internationalizing the RMB, the market has created a second exchange rate for the currency. Over the past few years, the CNH exchange rate has attracted increasing interest from market participants, policymakers, and academics. In the current study, we find that the microstructure approach offers a good framework to describe the recently formed CNH exchange rate. The explanatory power of the CNH order flow variable, for example, is quite comparable to existing microstructure studies on exchange rates (King, et al., 2013). In addition the contemporaneous effect, the order flow has lagged effect on the return of CNH exchange rate. The limit order imbalance, another microstructure variable, also exhibits the expected effect.

Interestingly, these microstructure variables also affect the variations in the CNY exchange rate, albeit their effects are weak. Attesting to the general belief that the RMB exchange rate is heavily managed by policy measures, we found both CNH and CNY exchange rates adjusted to their deviations from the official central parity rate, and changes in the central parity rate itself.

The onshore and offshore exchange rates exhibit both long-term and short-term interactions. On the average the offshore CNH rather than the onshore CNY adjusts to deviations from their estimated long-term relationship. Subsample results, however, show that the short-term causal relationship between the two exchange rates of the same currency RMB changes over time. The trading conditions in the two segregated markets could vary according to market situations. Our results show that the effect of the CNH exchange rate on the onshore rate is stronger towards the end of our sample period, while the effect of the onshore rate on the offshore one is stronger in the earlier period.

The existence of two deliverable exchange rates for a currency is quite special. Under tight capital controls investors may trade the offshore alternative in order to get exposure to the onshore market. Indeed, price discovery is a presumed function of the offshore exchange rate. Our analysis indicates that information embedded in the offshore RMB foreign exchange market may have implications for the (unobserved) market-based RMB exchange rate. The two offshore market variables; the CNH return and the CNH order flow are found to have a predictive power for the official RMB central parity rate.

Our study revealed several interaction patterns between the offshore and onshore markets. There are some issues warrant further analyses. For instance, it will be of interest to identify the economic forces including market infrastructure that drive the inter-market information flow. Also, why does the short-term causation pattern between the offshore and onshore rates change over time? Through what channel developments in the offshore market affect the onshore market exchange rate? Do the Chinese authorities incorporate the information from the offshore market in determining the RMB central parity rate?

Data Appendix

Notation	*Variable*	*Source*
Y_t	CNY exchange rate	Ecowin
H_t	CNH exchange rate	Ecowin
$vola_t$	J.P. Morgan, EM-VXY Currency Volatility Index	Ecowin
F_t	CNH-USD three-month interest rate differential	DataStream
ΔX_t	Net order flow/trading volume	Reuters D2000-2, and authors own calculations
$LOIm_t$	Net Limit order book imbalance/trading volume	Reuters D2000-2, and authors own calculations
P_t	The RMB central parity rate	People's Bank of China

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Table 1. The CNH Exchange Rate and Microstructure Variables

	(1)	(2)	(3)	(4)
Constant	-.013	-.013	-.008	-.007
	(-1.98)	(-2.08)	(-1.37)	(-1.30)
ΔF_t	.039	.018	-.019	-.02
	(1.38)	(.65)	(-.78)	(-.82)
ΔH_{t-1}	-.085	-.114	-.123	-.123
	(-.76)	(-1.08)	(-.95)	(-.94)
$\Delta vola_t$		2.196	2.244	2.205
		(3.94)	(4.22)	(4.15)
ΔX_t			.095	.092
			(5.55)	(5.45)
$LOIm_t$				.006
				(2.11)
Adj. R2	.01	.08	.20	.21

Note: The table presents the results of estimating $\Delta H_t = \alpha + \beta\Delta X_t + \gamma\Delta F_t + \varepsilon_t$. H, X, and F are defined in the text. $\Delta vola_t$ is the change in the JP Morgan emerging markets currency volatility index, and $LOIm_t$ is the limit-order imbalance. Adjusted R-squares estimates are provided in the row labeled "Adj. R2." Roubust t-statistics are given in parentheses underneath coefficient estimates.

Table 2. The VECM of (H_t, X_t, F_t)

	ΔH_t	ΔX_t	ΔF_t
EC_{t-1}	-.0264	1.5538	-2.0404
	(-3.07)	(.74)	(-2.46)
ΔH_{t-1}	-.0986	-5.5316	-4.1240
	(-2.65)	(-.61)	(-1.15)
ΔX_{t-1}	.0004	.0011	.0137
	(2.74)	(.03)	(.92)
ΔF_{t-1}	-.0005	.0864	-.2936
	(-1.46)	(1.00)	(-8.58)
Constant	-.0001	-.0143	.0021
	(-1.93)	(-.91)	(.34)
Adj. R2	.0283	-.0026	.1006

Note: The table presents the results of estimating the VECM specifications:

$$\Delta H_t = \alpha_1 + \delta_1 EC_{t-1} + \phi_1 \Delta H_{t-1} + \beta_1 \Delta X_{t-1} + \gamma_1 \Delta F_{t-1} + \varepsilon_{1t},$$

$$\Delta X_t = \alpha_2 + \delta_2 EC_{t-1} + \phi_2 \Delta H_{t-1} + \beta_2 \Delta X_{t-1} + \gamma_2 \Delta F_{t-1} + \varepsilon_{2t},$$

and

$$\Delta F_t = \alpha_3 + \delta_3 EC_{t-1} + \phi_3 \Delta H_{t-1} + \beta_3 \Delta X_{t-1} + \gamma_3 \Delta F_{t-1} + \varepsilon_{3t},$$

where the lag structure is determined by information criteria. EC_t is the estimated error correction term, with the trend and constant included, and is given by H_t -.0012 X_t +.0108 F_t, and the robust t-statistics of the two coefficient estimates are, respectively, -1.85 and 2.87. Adjusted R-squares estimates are provided in the row labeled "Adj. R2." Roubust t-statistics are given in parentheses underneath coefficient estimates.

Table 3. The VECM (H_t, X_t, F_t) specification of the CNH exchange rate return: with augmented variables

	(1)	(2)	(3)	(4)	(5)
Constant	-.0001	-.0001	-.0001	-0.0001	-0.0001
	(-1.96)	(-2.08)	(-1.16)	(-1.24)	(-1.01)
EC_{t-1}	-.0264	-.0187	-.0080	-0.0073	-0.0093
	(-3.07)	(-2.24)	(-1.06)	(-0.98)	(-1.31)
ΔH_{t-1}	-.0986	-.1215	-.1141	-0.1590	-0.1405
	(-2.65)	(-3.37)	(-2.96)	(-3.97)	(-3.67)
ΔX_{t-1}	.0004	.0003	.0002	0.0003	0.0003
	(2.74)	(2.02)	(1.85)	(2.19)	(2.27)
ΔF_{t-1}	-.0005	-.0005	-.0003	-0.0005	-0.0007
	(-1.46)	(-1.51)	(-1.07)	(-1.41)	(-2.26)
$\Delta vola_t$		.0207	.0219	0.0227	0.0208
		(7.60)	(9.00)	(9.07)	(8.69)
$LOIm_{t-1}$			.0001	0.0000	0.0000
			(1.76)	(0.93)	(1.22)
$LOIm_t$				0.0001	0.0000
				(2.90)	(1.64)
ΔX_t					0.0010
					(7.90)
Adj. R2	.03	.10	.12	0.15	0.23

Note: The table presents the results of estimating $\Delta H_t = \alpha_1 + \delta_1 EC_{t-1} + \phi_1 \Delta H_{t-1} + \beta_1 \Delta X_{t-1} + \gamma_1 \Delta F_{t-1} + \partial Z_t + \varepsilon_{1t}$, where Z_t include the change in the JP Morgan emerging markets currency volatility index ($\Delta vola_t$), contemporaneous and lagged limit order imbalances ($LOIm_t$ and $LOIm_{t-1}$), and contemporaneous order flow (ΔX_t). Adjusted R-squares estimates are provided in the row labeled "Adj. R2." Roubust t-statistics are given in parentheses underneath coefficient estimates.

Table 4. The VECM of (Y_t, H_t)

	ΔY_t	ΔH_t
EC_{t-1}	.001416	.065539
	(.15)	(4.21)
ΔY_{t-1}	-.14084	.049671
	(-3.47)	(.73)
ΔY_{t-2}	-.01664	.121189
	(-.41185)	(1.79200)
ΔH_{t-1}	.022432	-.08021
	(.93)	(-1.98)
ΔH_{t-2}	.039698	-.08132
	(1.66)	(-2.03)
Constant	-.00013	-.00012
	(-3.29)	(-1.80)
Adj. R2	.013	.037

Note: The table presents the results of estimating the VECM specifications:

$$\Delta H_t = \alpha_1 + \delta_1 EC_{t-1} + \phi_{11}\Delta H_{t-1} + \phi_{12}\Delta H_{t-2} + \beta_{11}\Delta Y_{t-1} + \beta_{12}\Delta Y_{t-2} + \varepsilon_{1t},$$

and

$$\Delta Y_t = \alpha_2 + \delta_2 EC_{t-1} + \phi_{21}\Delta H_{t-1} + \phi_{22}\Delta H_{t-2} + \beta_{21}\Delta Y_{t-1} + \beta_{22}\Delta Y_{t-2} + \varepsilon_{2t,}$$

where the lag structure is determined by information criteria. The error correction term EC_{t-1} is given by $(Y_{t-1} - 1.0735H_{t-1})$, and the robust t-statistic of the estimates is -27.78. Adjusted R-squares estimates are provided in the row labeled “Adj. R2.” Roubust t-statistics are given in parentheses underneath coefficient estimates.

Table 5A. The VECM(Y_t, H_t) specifications of the CNY and CNH exchange rate returns: with augmented variables

	(1)		(2)		(3)		(4)		(5)	
	ΔY_t	ΔH_t	ΔY_t	ΔH_t	ΔY_t	ΔH_t	ΔY_t	ΔH_t	ΔY_t	ΔH_t
Constant	-.0001	-.0001	-.0001	-.0001	-.0001	-.0001	-.0001	-.0001	-0.0001	0.0000
	(-3.29)	(-1.80)	(-3.41)	(-1.92)	(-3.41)	(-1.92)	(-3.42)	(-1.92)	(-2.59)	(-0.70)
EC_{t-1}	.0014	.0655	-.0036	.0543	-.0032	.0547	-.0031	.0545	0.0025	0.0696
	(.15)	(4.21)	(-.39)	(3.61)	(-.35)	(3.63)	(-.34)	(3.62)	(0.26)	(4.86)
ΔY_{t-1}	-.1408	.0497	-.1256	.0839	-.1240	.0857	-.1216	.0749	-0.0556	-0.0419
	(-3.47)	(.73)	(-3.15)	(1.28)	(-3.10)	(1.31)	(-3.03)	(1.14)	(-1.25)	(-0.65)
ΔY_{t-2}	-.0166	.1212	-.0191	.1143	-.0198	.1134	-.0194	.1117	-0.0239	0.1187
	(-.41)	(1.79)	(-.48)	(1.75)	(-.50)	(1.74)	(-.49)	(1.72)	(-0.53)	(1.83)
ΔH_{t-1}	.0224	-.0802	.0043	-.1208	.0054	-.1196	.0083	-.1325	-0.0009	-0.1043
	(.92)	(-1.98)	(.18)	(-3.06)	(.22)	(-3.03)	(.34)	(-3.31)	(-0.03)	(-2.40)
ΔH_{t-2}	.0397	-.0813	.0371	-.0856	.0378	-.0847	.0378	-.0847	0.0423	-0.0417
	(1.66)	(-2.03)	(1.57)	(-2.21)	(1.60)	(-2.19)	(1.60)	(-2.19)	(1.48)	(-1.01)
$\Delta vola_t$			.0091	.0213	.0090	.0211	.0091	.0206	0.0077	0.0202
			(5.58)	(7.93)	(5.49)	(7.85)	(5.53)	(7.63)	(4.68)	(8.53)
ΔF_t					.0002	.0002	.0002	.0002	0.0001	-0.0001
					(.99)	(.68)	(1.01)	(.64)	(0.46)	(-0.42)
ΔX_{t-1}							-.0001	.0003	0.0000	0.0003
							(-.65)	(1.77)	(-0.19)	(2.44)
ΔX_t									0.0003	0.0010
									(3.87)	(8.04)
Adj. R2	.01	.04	.05	.11	.05	.11	.05	.11	0.06	0.25

Note: The table presents the results of estimating

$$\Delta H_t = \alpha_1 + \delta_1 EC_{t-1} + \phi_{11}\Delta H_{t-1} + \phi_{12}\Delta H_{t-2} + \beta_{11}\Delta Y_{t-1} + \beta_{12}\Delta Y_{t-2} + \partial_1 Z_t + \varepsilon_{1t},$$

and

$$\Delta Y_t = \alpha_2 + \delta_2 EC_{t-1} + \phi_{21}\Delta H_{t-1} + \phi_{22}\Delta H_{t-2} + \beta_{21}\Delta Y_{t-1} + \beta_{22}\Delta Y_{t-2} + \partial_2 Z_t + \varepsilon_{2t,}$$

where the vector Z_t include the change in the JP Morgan emerging markets currency volatility index ($\Delta vola_t$), the change in the three month CNH-US interest rate differential, contemporaneous and lagged order flow (ΔX_t and ΔX_{t-1}), contemporaneous and lagged limit order imbalances ($LOIm_t$ and $LOIm_{t-1}$), the change in the central parity rate (ΔP_t), and deviations from the central parity rate (P_t- H_{t-1} and P_t- Y_{t-1}). Adjusted R-squares estimates are provided in the row labeled "Adj. R2." Roubust t-statistics are given in parentheses underneath coefficient estimates.

Table 5B. The VECM(Y_t, H_t) specifications of the CNY and CNH exchange rate returns: with augmented variables

	(6)		(7)		(8)		(9)		(10)	
	ΔY_t	ΔH_t	ΔY_t	ΔH_t	ΔY_t	ΔH_t	ΔY_t	ΔH_t	ΔY_t	ΔH_t
Constant	-.0001	.0000	-.0001	.0000	-.0001	.0000	.0000	.0003	.0000	.0001
	(-2.60)	(-.71)	(-2.57)	(-.66)	(-1.42)	(.25)	(-.10)	(5.54)	(.00)	(2.31)
EC_{t-1}	.0026	.0718	.0029	.0726	-.0006	.0682	.0248	.2484	.0158	.1102
	(.26)	(5.00)	(.29)	(5.07)	(-.07)	(4.36)	(1.65)	(10.99)	(1.47)	(6.32)
ΔY_{t-1}	-.0576	-.0487	-.0593	-.0531	-.0890	-.0737	-.0985	-.1416	-.1020	-.1068
	(-1.28)	(-.75)	(-1.32)	(-.82)	(-2.16)	(-1.10)	(-2.39)	(-2.28)	(-2.49)	(-1.62)
ΔY_{t-2}	-.0229	.1180	-.0210	.1230	-.0084	.1598	-.0199	.0785	-.0206	.1287
	(-.51)	(1.81)	(-.47)	(1.89)	(-.20)	(2.36)	(-.48)	(1.26)	(-.50)	(1.94)
ΔH_{t-1}	-.0002	-.1068	.0000	-.1064	-.0238	-.1312	-.0170	-.0832	-.0173	-.1146
	(-.01)	(-2.44)	(-.00)	(-2.44)	(-.85)	(-2.86)	(-.60)	(-1.96)	(-.62)	(-2.54)
ΔH_{t-2}	.0419	-.0435	.0413	-.0450	.0493	-.0510	.0535	-.0216	.0525	-.0430
	(1.46)	(-1.05)	(1.44)	(-1.09)	(1.86)	(-1.17)	(2.01)	(-.54)	(1.99)	(-1.01)
$\Delta vola_t$	.0076	.0204	.0075	.0200	.0012	.0142	.0010	.0134	.0013	.0146
	(4.67)	(8.59)	(4.57)	(8.43)	(.76)	(5.65)	(.68)	(5.78)	(.85)	(5.91)
ΔF_t	.0001	-.0001	.0001	-.0001	.0001	-.0002	.0001	-.0001	.0001	-.0002
	(.49)	(-.33)	(.46)	(-.37)	(.45)	(-.51)	(.47)	(-.47)	(.47)	(-.49)
ΔX_{t-1}	-.0000	.000284	.0000	.0003	-.0001	.0003	-.0001	.0003	-.0001	.0003
	(-.24)	(2.05)	(-.19)	(2.15)	(-1.50)	(2.13)	(-1.59)	(1.92)	(-1.50)	(2.19)
ΔX_t	.0003	.0010	.0003	.0010	.0004	.0010	.0003	.0009	.0004	.0010
	(3.86)	(8.05)	(3.62)	(7.61)	(4.32)	(7.53)	(4.07)	(7.00)	(4.25)	(7.52)
$LOIm_{t-1}$	.0000	.0001	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
	(.15)	(1.85)	(-.02)	(1.52)	(-.49)	(1.08)	(-.46)	(1.34)	(-.33)	(1.37)
$LOIm_t$			.0000	.0001	.0000	.0001	.0000	.0001	.0000	.0001
			(1.13)	(2.04)	(1.75)	(2.24)	(1.71)	(2.22)	(1.79)	(2.32)
ΔP_t					.5707	.4197	.5707	.4199	.5671	.4105
					(13.28)	(5.97)	(13.32)	(6.51)	(13.30)	(5.96)
$P_t - H_{t-1}$							-.0170	-.1206		
							(-2.19)	(-10.32)		
$P_t - Y_{t-1}$									-.0230	-.0585
									(-3.19)	(-5.04)
Adj. R2	.06	.25	.06	.26	.28	.28	.29	.39	.29	.31

Note: See the Note to Table 5A.

Table 6A. The VECM(Y_t, H_t) specification of the CNY and CNH exchange rate returns: different subsamples

	September 30, 2010 – September 21, 2011		September 22, 2011 – April 13, 2012		April 14, 2012 – August 27, 2013	
	ΔY_t	ΔH_t	ΔY_t	ΔH_t	ΔY_t	ΔH_t
EC_{t-1}	0.0040	0.069	-0.0939	0.3083	0.0100	0.1464
	(0.30)	(2.98)	(-1.60)	(2.95)	(0.31)	(3.71)
ΔY_{t-1}	-0.1403	0.3250	-0.1295	-0.5949	-0.1448	0.1350
	(-2.03)	(2.70)	(-1.36)	(-3.50)	(-2.08)	(1.61)
ΔY_{t-2}	-0.0407	0.0389	0.0078	0.16067	0.0245	0.0776
	(-0.58)	(0.32)	(0.08)	(0.92)	(0.37)	(0.96)
ΔH_{t-1}	0.0363	-0.0743	-0.0535	0.0197	0.1555	-0.0534
	(0.92)	(-1.08)	(-1.05)	(0.22)	(2.81)	(-0.80)
ΔH_{t-2}	0.0395	-0.0649	0.0490	-0.0574	-0.0677	-0.1813
	(1.03)	(-0.97)	(0.97)	(-0.63)	(-1.26)	(-2.80)
Constant	-0.0002	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
	(-2.63)	(-1.05)	(-0.88)	(-0.66)	(-2.03)	(-1.72)
Adj. R2	-0.00	0.06	0.05	0.13	0.02	0.07

Note: See the Note to Table 4.

Table 6B. The VECM(Y_t, H_t) specification of the CNY and CNH exchange rate returns: p-values from the Granger causality test for different subsamples

	September 30, 2010 – September 21, 2011	September 22, 2011 – April 13, 2012	April 14, 2012 – August 27, 2013
ΔH ≠› ΔY	0.439	0.315	0.002
ΔY ≠› ΔH	0.026	0.001	0.242

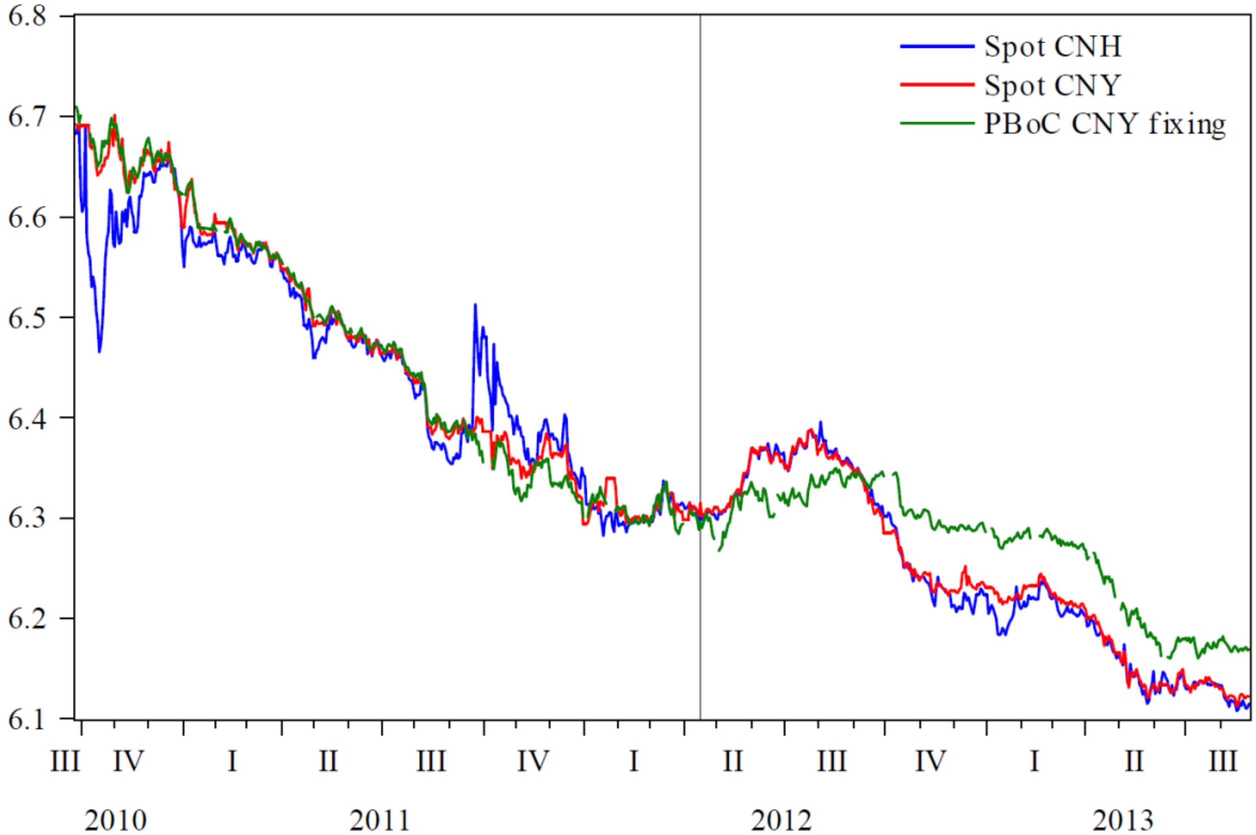
Note: Table presents p-values of the test of excluding lags in the short-run dynamics of the VECM. "ΔH ≠› ΔY" gives the p-values of testing the null hypothesis of ΔH does not cause ΔY; that is, the exclusion of lags of ΔH for the specification of ΔY. "ΔY ≠› ΔH" gives the p-values of testing the null hypothesis of ΔY does not cause ΔH.

Table 7. Out-of-sample forecasting of the change in the RMB central parity rate

	ΔH_{t-1}	ΔY_{t-1}	ΔX_{t-1}	RW
RMSE	0.541	0.547	0.538	0.546
	(0.84)	(-0.27)	(2.54)	
MAE	0.415	0.427	0.418	0.427
	(2.56)	(0.09)	(2.77)	

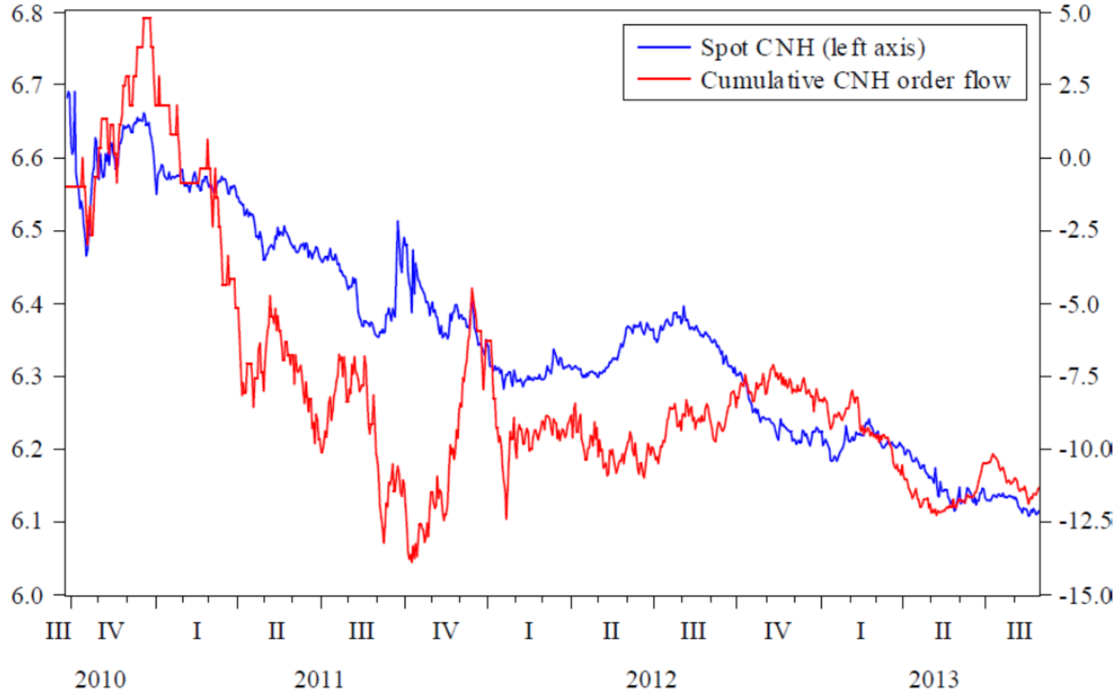
Note: Rows "RMSE" and "MAE" reports the Root Mean Squared prediction Errors and Mean Absolute prediction Errors for differences between the actual RMB central parity rate and the forecast of the central parity rate conditioned on lagged values of ΔH, ΔY, ΔX, or a constant. Numbers in parentheses are robust Diebold-Mariano *t*-statistics for testing the significant difference between the random walk forecast and the alternative forecast. A positively significant statistic means the random walk forecast has a larger error.

Figure 1. CNH exchange rate, CNY exchange rate, and the RMB Central Parity Rate



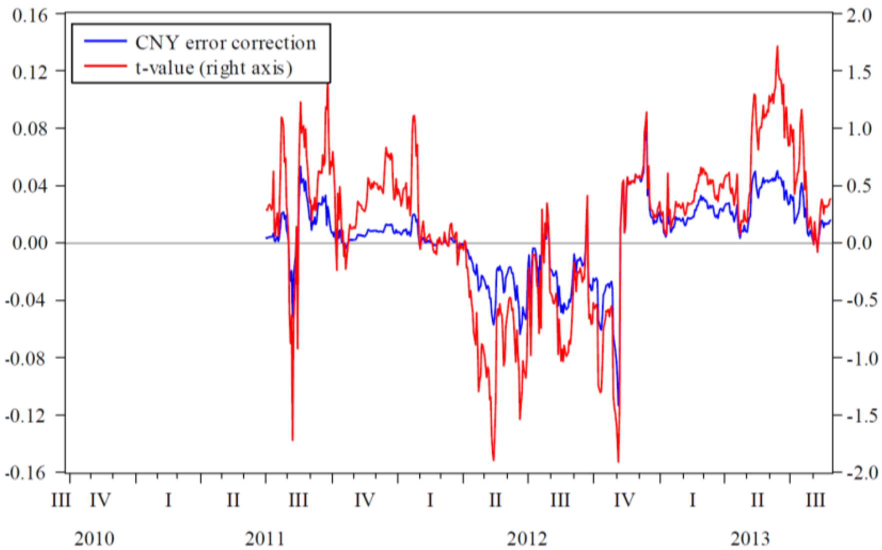
Note: The figure shows the offshore CNH/USD, the onshore CNY/USD and the RMB/USD central parity rate. The central parity rate is fixed each morning, while the two other rates are sampled at the end of day. The sample period is September 27, 2010 to August 27, 2013. The vertical line denotes April 14, 2012, the date the trading band was widen from ±0.5% to ±1% Data are from the People's Bank of China website, Ecowin, and DataStream.

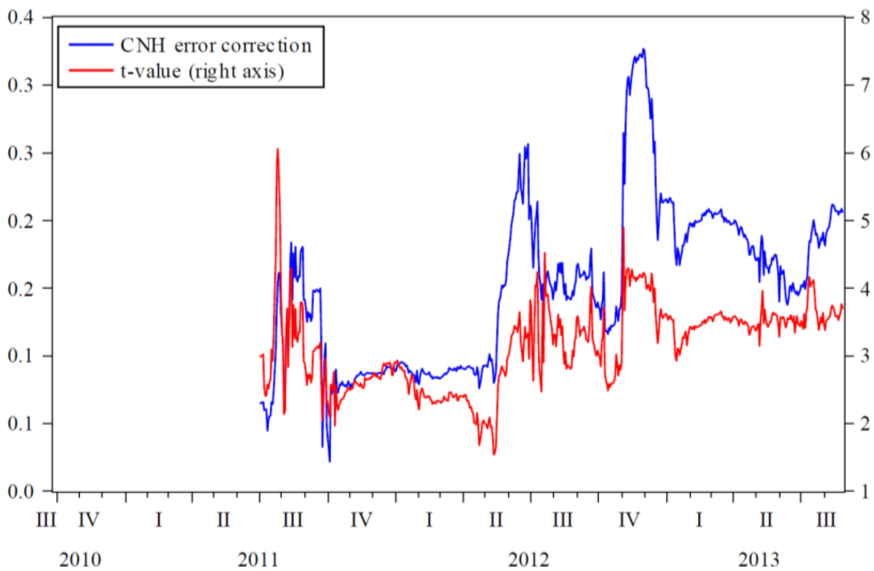
Figure 2. CNH Exchange Rate and Accumulated CNH Order Flow



Note: The figure shows the offshore CNH/USD (left axis) and the cumulative normalized CNH/USD order flow. See the text for the definition of the order flow. The sample period is September 27, 2010 to August 27, 2013. Data are from Reuters D2000-2 and Ecowin.

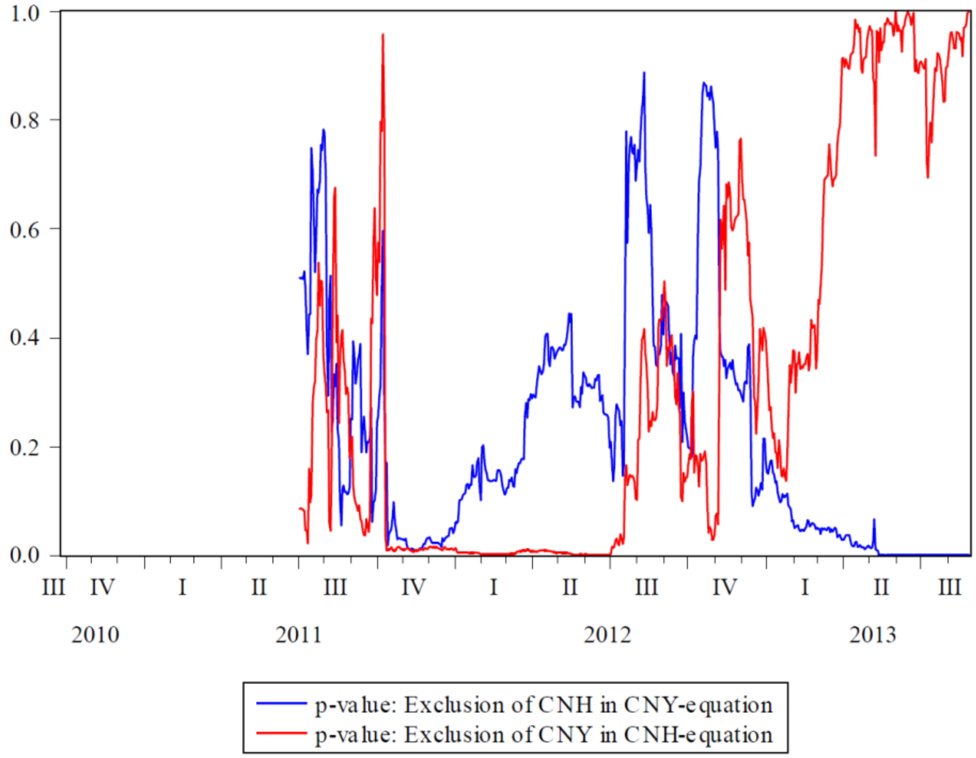
Figure 3. Rolling Estimates of Error-Correction Coefficient Estimates and their t-Statistics





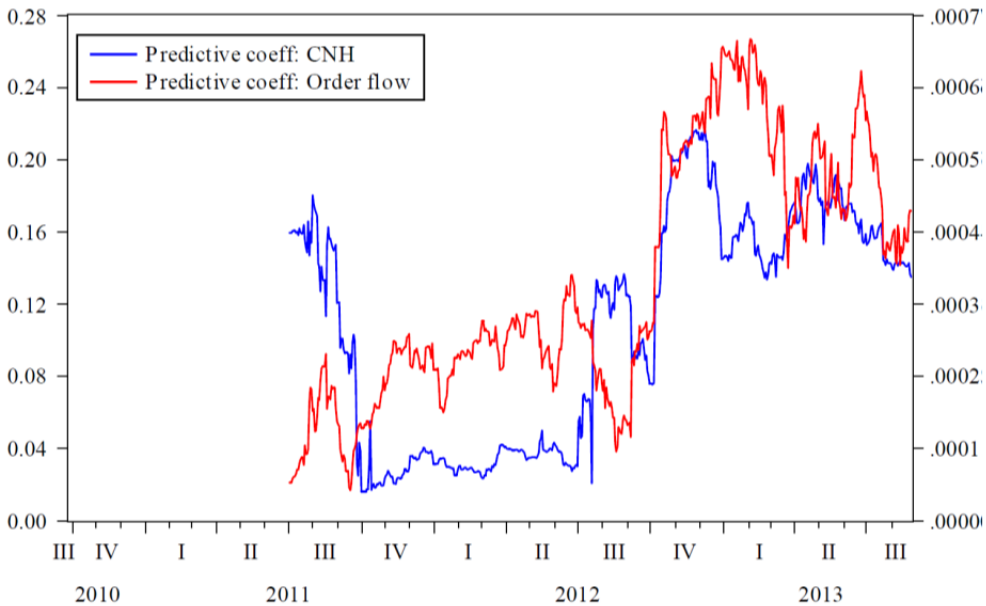
Note: The upper panel shows the rolling coefficient estimates of the error correction term in the CNY equation (left scale) and their corresponding t-statistics (right axis). The lower panel gives the same information of the CNH equation. The rolling estimates of the VECM are based on a moving window of 200 observations. The sample period is September 27, 2010 to August 27, 2013.

Figure 4. P-values of Rolling Block Exogeneity Test Statistics



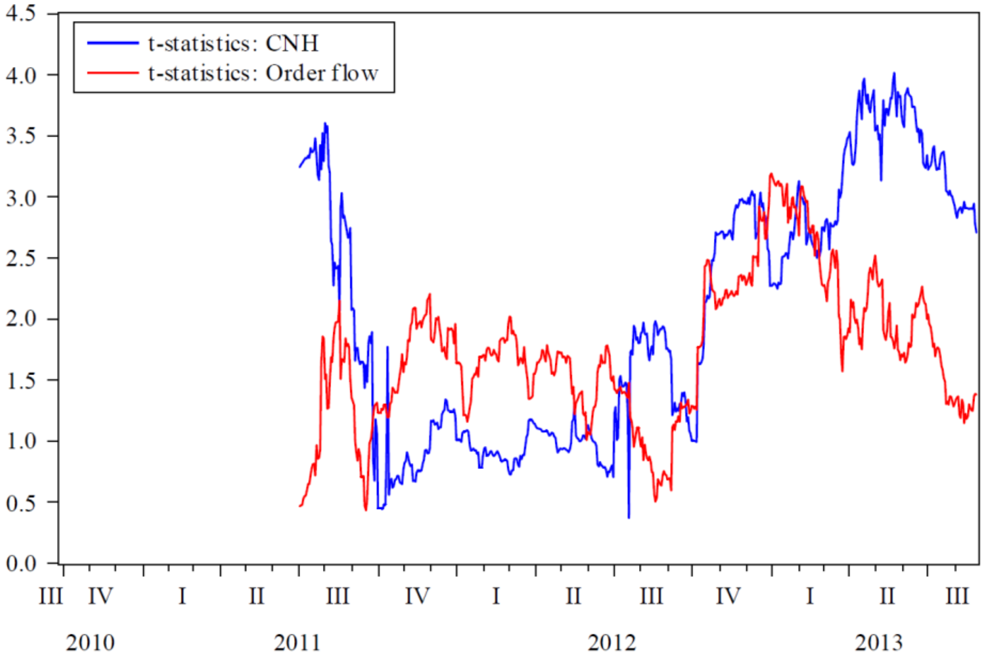
Note: The graph shows the p-values of a Wald-test statistic for the exclusion of lags of CNY in the equation for CNH, and vice versa. A low p-value means that one can reject the exclusion of the lags of, for example, CNY in the equation for CNH (and vice versa). The rolling estimates of the VECM are based on a moving window of 200 observations. The sample period is September 27, 2010 to August 27, 2013.

Figure 5. Rolling Estimates of Lagged CNH Return and Order Flow



Note: The figure shows the rolling coefficient estimates from equation (9); $\Delta P_t = \alpha + \beta_1 \Delta H_{t-1} + \beta_2 \Delta X_{t-1} + \varepsilon_t$ in the text. The rolling estimates are based on a moving window of 200 observations. The sample period is September 27, 2010 to August 27, 2013.

Figure 6. t-values of Rolling Estimates of Lagged CNH Return and Order Flow



Note: The figure shows the t-values of the rolling coefficient estimates presented in Figure 5. The sample period is September 27, 2010 to August 27, 2013.