Cointegration and Causality among the Onshore and Offshore Markets for China's Currency

Owyong, David and Wong, Wing-Keung and Horowitz, Ira

BOCI-Prudential Asset Management, Department of Economics, Hong Kong Baptist University, Information Systems and Operations Management, Warrington College of Business, University of Florida; Department of Economics, Hong Kong Baptist University

11 October 2015

Cointegration and Causality among the Onshore and Offshore Markets for China's Currency

David Owyong
BOCI-Prudential Asset Management

Wing-Keung Wong[1]
Department of Economics
Hong Kong Baptist University

Ira Horowitz
Information Systems and Operations Management
Warrington College of Business, University of Florida
Department of Economics, Hong Kong Baptist University

October 11, 2015

Acknowledgments: With the traditional disclaimer, we thank Professor Calla Wiemer, the Editor-in-Chief, the anonymous Associate Editor, and two anonymous referees for their most helpful and constructive comments and suggestions. The second author would like to thank Robert B. Miller and Howard E. Thompson for their continuous guidance and encouragement. This research was partially supported by Hong Kong Baptist University and the Research Grants Council of Hong Kong. The views expressed in this paper are those of the authors and do not necessarily reflect the views of the organizations to which they belong or the RGC.

[1] Corresponding author: Wing-Keung Wong, Department of Economics, Hong Kong Baptist University, WLB, Shaw Campus, Kowloon Tong, Hong Kong, Tel: (852) 3411-7542, Fax: (852) 3411-5580, email: awong@hkbu.edu.hk

Cointegration and Causality among the Onshore and Offshore Markets for China's Currency

Abstract

China has taken steps to develop offshore markets for renminbi trading and to liberalize exchange-rate determination in its onshore market. We examine the interaction between onshore and offshore markets with attention to how the interaction has been affected by widening of the onshore trading band first in April 2012 and further in March 2014. Ties between the onshore and offshore markets were closest before the first band widening and steadily loosened thereafter. We further study the cointegration and lead-lag effects between offshore and onshore spot and forward markets and show that there is a long-term equilibrium relationship between any pair of them. Our results suggest stronger causality running from the spot onshore rate to the spot offshore rate than vice versa. Between the spot and forward markets, there is evidence of bidirectional linear and nonlinear causality, which implies foreign impulses have had an influence on the domestic market.

Keywords: RMB; onshore and offshore markets; spot and forward markets; liberalization; cointegration

1. Introduction

The offshore spot market for the Chinese renminbi (RMB), commonly known as the CNH market, has grown phenomenally since its inception in July 2010. Forward markets were also established for both onshore and offshore transactions. Another mature market used for offshore forward transactions is the non-deliverable forward (NDF) market, which was specially established for the not-fully-convertible currencies of countries with capital controls. Thus there are now three forward markets for the RMB, prompting interest in their lead-lag relationships with the spot markets. While the onshore market is more established, it faces restrictions and controls by the Chinese central bank. By contrast, the offshore markets are more likely to reflect market sentiment and expectations. Transactions on the CNH market, which is relatively new, are based on the underlying currency, giving it an advantage over an NDF market that is entirely settled in US$ and is expected to dry up as the RMB becomes fully convertible.

China has been rapidly liberalizing its currency, stock, and bond markets in recent years. To enhance exchange-rate flexibility, in April 2012 and again in March 2014, the Chinese authorities widened the daily foreign exchange trading band, first from ±0.5% to ±1% and then to ±2%. This band governs the permitted degree of fluctuation in the currency within a trading day and determines the extent to which the RMB's movements reflect market forces rather than governmental guidance. The band was initially set at ±0.3% in 1994 and stood for over a decade, before it was raised to ±0.5% in 2007, which predated the formation of the overseas CNH market that we investigate in this paper. The widening of the bands have potentially far-reaching implications for the RMB in both its onshore and offshore markets. For instance, this widened band became critical when the Chinese central bank announced a surprise devaluation of the RMB by 1.86% on August 11, 2015 in an effort to revive China's flagging economy, thus pushing the exchange rate to the lower bound of that widened range.

Earlier studies considered the lead-lag effects between the forward NDF rates and the onshore spot rate, noting that the two markets were driven by different participants with different exchange-rate expectations. Our study does not suffer from this peculiarity, because the sample period is restricted to a time when the onshore forward markets, as well as the offshore CNH spot and forward markets, were in operation. In addition, we consider: (a) both cointegration and Granger causality between corresponding pairs of onshore and offshore exchange rates; (b) nonlinear Granger causality (Baek and Brock, 1992; Hiemstra and Jones, 1994; Bai et al., 2011, 2012); (c) one-period-ahead forecasts of out-of-sample data (Chiang et al., 2010); and sub-period cointegration and causality of the daily exchange rates for the same time horizon (e.g. spot versus spot, one-month forward versus one-month forward, etc). This horizon-matching is crucial in uncovering the differences in causal behavior across the different time horizons.

Among the most closely-related papers that have preceded ours, Peng et al. (2007) also noted that NDF pricing efficiency is restricted by the lack of a benchmark spot curve. We sidestep this difficulty by including the new CNH market, which has a spot market akin to its onshore counterpart, and the results are the same whether NDF or CNH exchange rates are used to represent the offshore rates, thus eliminating the possibility of this effect adversely affecting our inferences.

The more recent Ding et al. (2013) study of the new CNH, NDF, and onshore markets suffers from relying upon a relatively small sample, which may have masked the cointegration between the onshore market and the two offshore markets that our more extensive sample brings to light, a result that is consistent with the literature at large. Previously, Colavecchio and Funke (2008) employed multivariate GARCH models to study volatility spillovers between the Chinese non-deliverable forward market and seven of its Asia-Pacific counterparts, while Colavecchio and Funke (2009) applied SWARCH models to study the volatility dependence across Asia-Pacific onshore and offshore currency forward markets. To the best of our knowledge, ours is the first paper to cut as wide a swath as we do and apply it to such an extensive data base.

By comparing the RMB exchange rate in the onshore and offshore markets in terms of spot and forward rates (one-month, three-month, six-month, and 12-month), we are able to determine whether the causality properties differ across different time horizons, which was indeed revealed to be the case.

In particular, we find that all of the daily exchange rates of the Chinese RMB onshore (CNY), offshore (CNH), and offshore non-deliverable forward markets (NDF) have a unit root of order one. In addition, differing from the findings of no cointegration (see, for example, Ding et al., 2013) and cointegration (see, for example, Yang and Leatham, 2001) in the literature, we find that all pairs are cointegrated, thus implying that there exists a long-term equilibrium relationship between any pair of those markets and the offshore non-deliverable forward markets. Still further, since all our data series are shown to be first-order integrated, using an error-correction mechanism we examine whether there is any Granger causality between the markets. And indeed, for the spot markets we find that there is stronger causality running from the onshore exchange rates to the offshore rates, but that there tends to be more symmetrical bidirectional causality in the forward markets. This suggests that domestic market participants have an informational edge over those in the offshore markets, but only in the very short term. In the short term, rumors regarding central bank moves, policy changes, data releases, and other transient factors may draw more attention, hence giving the domestic market an advantage. Nevertheless, we also find that there is a strong nonlinear causal relationship between any pair of the daily exchange rates, which in turn, implies that there exist some nonlinear relationships among the markets.

Our sub-period analysis shows that the ties between exchange rates differ in the three sub-periods that are delineated by the two breakpoints of April 14, 2012 and March 15, 2014. The former marks the announcement of the widening of the exchange-rate band from ±-0.5% to ±1%, the latter from ±1% to ±2%. The differences are initially suggested by the descriptive statistics for the three sub-periods. Subsequent stationarity tests show that (a) all the exchange rates in sub-period 1 are stationary, (b) some exchange rates are stationary and some are not in sub-period 2, and (c) all exchange rates follow random walks in sub-period 3. This finding implies that the exchange-rate movements were most predictable in sub-period 1, became less so in sub-period 2, and were basically random in sub-period 3.

The findings of our cointegration analysis in the sub-periods are also striking. We find that the "cointegration" coefficients from the onshore and offshore exchange rates are close to unity in the first sub-period, move away from unity in the second sub-period, and drift far away from it in the third-sub-period. This further implies that the ties between the onshore and offshore markets were closest during the first sub-period, with hints of causality therein, before steadily loosening thereafter. Our forecasting analysis shows the out-of-sample causality forecasts to, on occasion, be consistent with that of the in-sample estimates. We also find many cases, however, in which, anomalously, those forecasts match in one direction (e.g., up) but do not match in the other (e.g., down).

Our results affirm the findings of Tian and Chen (2013) that the RMB is heavily influenced by the interventions of the Chinese central bank, and so these moves should be felt in the onshore market. The appreciating RMB has, for instance, led to speculative capital inflows whose onshore impact the Chinese authorities - that is, the central bank – were able to effectively neutralize on a sustained basis (Ouyang et al., 2010). Given the frequent intervention of the Chinese authorities and the greater influence they wield over the onshore market, the direction of causality should therefore run more strongly from there to the offshore market, which we found to be true for the spot exchange rate, which the central bank directly influences. Our findings are also consistent with those of Liu and Pauwels (2012), who found that external political pressures from outside China did not affect the levels of either the onshore or the offshore exchange rates. If external political pressure had been a factor, we should have found stronger causality from the offshore to the onshore markets, since the former would have an advantage in such news.

Our main goal is to determine the impact of the widening of the permissible band for the RMB exchange rate on the dynamics between the various onshore and offshore RMB markets. These band-widening moves are expected to materially affect the interrelationships between these markets because of the enhancement of exchange-rate flexibility in the onshore RMB market. As the onshore exchange rate becomes more flexible, it would better reflect the same market forces that drive the offshore markets, which would imply a stronger causal effect running from the offshore to the onshore rates. In addition, the greater onshore exchange-rate flexibility would also help to transmit onshore information overseas through price movements, thus strengthening the signaling function of the onshore RMB exchange rate to market participants abroad.

After the two exchange-rate-band-widening moves in 2012 and 2014, the greater flexibility of the onshore exchange rate would plausibly cause it to be more influenced by the market forces that drive the offshore markets. This would in turn result in the offshore and onshore RMB levels becoming increasingly in step with each other. When this liberalization is carried to the extreme, one would anticipate the onshore and offshore markets to become one single homogenous market. Given this, we expect the causality between the offshore and onshore RMB to decline after each of the band-widening moves, as the two exchange rates increasingly move in step with each other.

The paper proceeds as follows. The next section provides a brief literature review, which is followed by a discussion of data issues and our approach. We present our empirical results in Section 4 and discuss our nonlinear causality results in Section 5. Section 6 presents the sub-period analysis and Section 7 that of the forecasts. We then draw our conclusions. The appendix presents an overview of the various Chinese currency markets.

2. Literature review

The NDF market started in the early 1990s, and the forward rates for the Asian currencies received much more attention after the Asian currency crisis in 1997. In addition to the papers cited in the previous section, several others are directly related to our work, and in the interests of completeness, we briefly mention them here.

Fung et al. (2004) provide a detailed description of the NDF market for the RMB. A number of researchers have examined the relationship between the onshore spot and the offshore NDF exchange rates for various currencies (Cadarajat and Lubi, 2012; Park and Rhee, 2001; Gu and McNelis, 2013). Among those studies that focused on the RMB, Yang and Leatham (2001) found the offshore NDF and onshore CNY exchange rates to be cointegrated, although this cointegration emerged only after partial currency convertibility was allowed in March 1996. Ding et al. (2013) failed to detect cointegration with a very short 21-month sample period. In general, the evidence in the literature is supportive of cointegration, whether for the RMB or for other currencies, with NDF markets (Park, 2001; Jeon and Seo, 2003). This might lead one to anticipate that while the onshore and offshore RMB exchange rates may diverge in the short term, in the long term they will tend to move in tandem.

The natural question thus arises as to whether there is Granger causality in either one or both directions between the onshore and offshore exchange rates. The literature has reported mixed results. For instance, Peng et al. (2007) noted that, despite trading and capital restrictions, sentiment can spill over between the onshore and offshore markets and that over time the relative contribution of price leadership has shifted between the onshore and offshore centers. We provide a more complete answer in the work that follows.

3. Data and approach

The sample period starts from the date at which the offshore RMB market was established, which is August 23, 2010. The sample period ends at the end of 2014, which covers the two

RMB band-widening moves in April 2012 and March 2014. These two dates then become the breakpoints at which we will analyze whether there has been any impact on the interconnectedness of the various RMB markets.

Our data comprise the daily exchange rates for the RMB onshore (CNY), offshore (CNH), and offshore non-deliverable forward markets (NDF). CNY refers to the onshore forward exchange rate at the different respective time horizons, including 0, 1, 3, 6, and 12 months in which CNY 0-month refers to the onshore RMB (0-month) spot rate and CNYxM refers to the x-month-ahead onshore forward exchange rate for x=1, 3, 6, and 12. CNHxM refers to the x-month-ahead offshore forward exchange rate and NDFxM refers to the x-month-ahead offshore forward exchange rate in the offshore non-deliverable forward markets for x = 1, 3, 6, and 12. In addition, we have the CNH spot rate, which is the offshore RMB spot rate, or simply the offshore RMB. Each of the three RMB markets (CNY, NDF, and CNH) involves four forward exchange rates, and there are two RMB spot markets (onshore and offshore). Thus we will be working with a grand total of 3*4 + 2 = 14 basic time series.

All data are from Bloomberg. Daily data are used from August 23, 2010 to January 31, 2015. We use the data from August 23, 2010 to December 31, 2014 to undertake a Granger causality analysis to determine the causality relationships between all pairs of corresponding forward markets (i.e, 1M, 3M, 6M, and 12M) in the three RMB markets. Specifically, the four CNY and CNH pairs, the four CNY and NDF pairs, and the four CNH and NDF pairs. , as well as the pairing of the two spot markets. Since in principle, at least, any causality can run in either direction, we will be determining 4*3*2 + 2 = 26 possible causality relationships. When we cannot reject Granger causality in either direction between any market pair for a corresponding forward market, we have bidirectional Granger causality. Moreover, we undertake that analysis for both linear and nonlinear causality. We then use the data from January 1, 2015 to January 31, 2015 for forecasting purposes, based on the linear-causality results. .

In this paper, we study whether there is any impact in different stages of the liberalization of the RMB and the impact of the widening of the RMB exchange-rate band within which the currency is allowed to fluctuate. To do so, we divide our data into three sub-periods in accordance with the two breakpoints established by the widening of the RMB exchange-rate band so that each sub-period represents a different stage of the liberalization of the RMB. To study the relationship between the CNY, CNH, and NDF at the different respective time horizons in each sub-period, we examine the possibility of a unit root for each series and the cointegration and linear and nonlinear causality relationship between two series of CNY, CNH, and NDF at the different respective time horizons.

We proceed as follows. We first hypothesize that there are two break points for the RMB, stemming from two events: (1) a first widening of the exchange-rate band from ±-0.5% to ±1% on April 14, 2012; and (2) a second widening of the exchange-rate band from ±1% to ±2% on March 15, 2014. Employing a Perron test (Perron, 1989), we determine that all 14 of our data series have a unit root with structural breaks on these two critical dates, which supports our two-break-point hypothesis. We further determine that subject to those two breaks the data series are cointegrated of order $I(1)$. The breakpoints could reflect different stages of the liberalization of the RMB. In the first sub-period, when the band is narrow, the RMB is under strong control by the Chinese government. In the second sub-period, the RMB exchange rate is more liberal, while in the third sub-period, with the further widening of the band, the rate is yet more liberal.

To examine the co-movements among the three markets with these two breakpoints, let: (1) X_t and Y_t represent one of the 24 pairs of time series of comparable time-horizons developed by coupling two RMB markets; (2) D_{1t} (D_{2t}) denote a binary dummy variable that is equal to unity when t precedes April 14, 2012 (March 15, 2014) and is zero otherwise; and (3) ε_t denote a random-error term with the usual normality properties. We first estimate the cointegrating parameters δ_1 and δ_2 in Eq. (1):

$$Y_t = \delta_0 + \delta_1 D_{1t} + \delta_2 D_{2t} + \delta_3 X_t + \varepsilon_t \,. \qquad (1)$$

If the residuals of Eq. (1) are stationary, the two series X_t and Y_t are cointegrated with structural breaks on the identified dates. We take X_t and Y_t to be onshore and offshore rates of different forward time horizons because different horizons could have different impacts on any cointegration relationship.

We then go on to use an error-correction mechanism to examine whether exchange-rate changes in one market, such as an offshore RMB market, say CNH, Granger-cause changes in a second RMB market, such as the NDF market, with different lead-lag structures. We further explore whether given such causality it can be said to be unidirectional or bidirectional.

The Granger representation theorem states that if two variables, Y and X, are cointegrated, an error-correction term, $e_{Y,t-1} = Y_{t-1} - \hat{\delta}_0 + \hat{\delta}_1 X_{t-1}$, determined from Eq. (1), can be included in the following equations to test for Granger causality:

$$
\begin{aligned}
\Delta Y_t &= \alpha_0 + \alpha e_{Y,t-1} + \sum_{i=1}^{n} \alpha_{1i} \Delta Y_{t-i} + \sum_{j=1}^{m} \alpha_{2j} \Delta X_{t-j} + u_{1t}, \\
\Delta X_t &= \beta_0 + \beta e_{Y,t-1} + \sum_{i=1}^{n} \beta_{1i} \Delta X_{t-i} + \sum_{j=1}^{m} \beta_{2j} \Delta Y_{t-j} + u_{2t},
\end{aligned} \tag{2}
$$

where $\Delta Y_t = Y_t - Y_{t-1}$, $\Delta X_t = X_t - X_{t-1}$, n and m are the optimum lags, and u_{1t} and u_{2t} are random-error terms.

The existence of cointegration implies causality among the set of variables as manifested by $|\alpha| + |\beta| > 0$ where α and β denote speeds of adjustment (Engle and Granger, 1987). If we do not reject the hypothesis that $\alpha_{21} = \cdots = \alpha_{2m} = 0$ and $\alpha = 0$, then X_t, say the onshore CNY, does not Granger-cause Y_t, say the offshore CNH or the NDF. Similarly, the failure to reject $\beta_{21} = \cdots = \beta_{2m} = 0$ and $\beta = 0$ suggests that the offshore CNH or NDF does not Granger-cause the onshore CNY (Granger et al., 2000).

4. Empirical results

In this section we consider the empirical results, starting with some descriptive statistics for the various exchange rates individually. To see if there are differences caused by the band-widening policy, this is implemented for the three sub-periods as well as the entire sample period. In addition, the usual unit-root and cointegration tests are conducted in order to facilitate further analysis. Subsequently, we use causality tests to examine the relationships between the various onshore and offshore RMB markets, and examine how the band-widening moves led to changes in these relationships.

Table 1 presents the descriptive statistics for the daily exchange rates in the three RMB markets for the entire period, as well as for the three sub-periods partitioned by the two breakpoints. We defer our discussion of the results for the sub-periods to Section 6.

**** Table 1 about here***

The table shows that the means for all markets fall within a very narrow range, with an average of 6.3122. The skewness estimates reveal all series to be skewed to the right. As the exchange rate is measured in terms of RMB per US$, strengthening the RMB implies a declining exchange rate. The right-hand skew is consistent with a steeper decline at the beginning of the sample period, and a slower decline as time progressed, as shown in the time-series' plots of the daily exchange rates for the 12-month futures for the three markets, in Fig. 1. This finding provides evidence to support the conjecture that there have been pressures on the government to allow, and indeed to encourage, the currency to appreciate. The plots for other time frames, which are not displayed here, show similar patterns.

**** Figure 1 about here ***

Table 1 shows larger variances and thinner-than-normal tails for most of the onRMB (onshore RMB), offRMB (offshore RMB) markets with earlier expiration dates. The markets with 12-month expiration dates and the NDF with a 6-month expiration date, however, possess fatter-than-normal tails. In addition, all exchange rates show levels of skewness and kurtosis that imply non-normality, which is confirmed by the statistically-significant ($\alpha = 0.01$) Jarque-Bera statistics for all rates.

Together with the fact that the RMB is appreciating against the US$, as shown in Fig. 1, highly significantly-positive kurtosis on the markets with a 12-month expiration date implies that there is an opportunity for highly profitable investment therein. Thus it makes sense that investors have to pay marginally higher prices when buying in those markets. Indeed, Table 1 reveals that the means of OnCNY12M, OffNDF12M, and OffCNH12M are 6.3292, 6.3514, 6.3161, respectively, each of which is higher than the corresponding rates in other time horizons, The latter observation supports the conjecture that there is a strong incentive for foreign investors to place their bets on the RMB, especially when purchasing in those markets.

To lend further support for our hypothesis that all of our data series have structural breaks on both April 14, 2012 and March 15, 2014, we employ the Perron unit-root test, the results of which are reported in Table 2. The table shows that none of the series are stationary ($\alpha = 0.01$) with the two significant breakpoints,[2] while their differences, ΔCNY, ΔCNH, and ΔNDF *are* stationary ($\alpha = 0.01$), with the two significant breakpoints. This implies that the CNY, NDF, and CNH data series are $I(1)$ with the two significant breakpoints ($\alpha = 0.01$).

****Table 2 about here***

We then compute the ADF statistic to test whether (a) the residuals have a unit root and (b) all the pairs are cointegrated with the two structural breaks. Since there is cointegration with the

---

[2] The offshore CNH 12M and offshore NDF12M are stationary ($\alpha = 0.05$) as are the offshore CNH 6M and the offshore NDF 6M rates (but only at $\alpha = 0.10$).

two breakpoints between all onshore-offshore exchange-rate pairs, and we expect the magnitudes of exchange-rate moves to differ across markets due to the different speeds of information transmission and hence the degree of overshooting. This expectation motivates our interest in testing whether the long-term cointegration is such that the dependent variable in Eq. (1) moves to a greater or lesser extent than does the independent variable, in response to movements in that variable: that is, is δ_3 greater than or less than unity. To make the determination, we conduct an *F* test of the hypothesis that $\delta_3 = 1$, or that in the long term the two series move together with corresponding changes. The results of the *F* test are reported in Table 3.

**** Table 3 about here ***

Pairing the CNY 3M and 12M with the corresponding CNHs, we cannot reject the unity hypothesis ($\alpha > 0.10$) that the series move together with corresponding changes. Pairing the CNHs and NDFs for all M, however, the estimate $\hat{\delta}_3$ is significantly less than unity ($\alpha < 0.1$), implying that over the long term the CNHs move to a lesser extent than do the corresponding NDFs for all M. Pairing the CNYs and CNHs for all M, $\hat{\delta}_3$ is significantly greater than unity in most pairs ($\alpha < 0.01$), implying that over the long term the CNYs move to a greater extent than do the corresponding CNHs for all M.

Our findings support our conjecture that, in general, the onshore exchange rates tend to move with a larger magnitude than do their offshore counterparts, suggesting a greater tendency for the RMB exchange rate to overshoot in the onshore market. A most plausible explanation for this tendency would be the less-rapid information flow in the domestic market relative to the offshore markets, leading traders to rely more on price movements as information, which in turn leads to a greater reliance on trend-following strategies. Such strategies are more likely to result in larger swings that involve overshooting, as well as larger corrections. A lower informational flow could also result in greater sensitivity of domestic participants to rumors, which could also lead to excessive exchange rate movements and subsequently larger reversals.

Since all variables are $I(1)$ with the two breakpoints, and there is cointegration with the two breakpoints between all onshore-offshore exchange-rate pairs, we next employ an error-correction model (ECM) (Sargan, 1964; Engle and Granger, 1987) to test whether there is any unidirectional or bidirectional relationship among the RMB onshore, offshore, and offshore non-deliverable forward markets. Specifically, we invoke the Johansen approach (Johansen, 1991) to test for the statistical significance of the ECM.

In the ECM, the number of lags to introduce is a key decision, and various informational criteria could recommend different lag lengths for the explanatory variable. Thus, different criteria could lead to conflicting results. To avoid these complications, we estimate Eq. (2) using all lags from one to 10. Since we are dealing with daily markets that are open five days a week, except during public holidays, this implies that we account for lead-lag effects of up to two weeks.

The main results of the Granger-causality test are reported in Table 4, and the detailed results of the estimated speeds of adjustment are reported in Table 5. The uppermost panel in Table 4 displays the causality results between the spot exchange rates in the onshore market (SPOTon) and the offshore CNH market (SPOToff). No spot rate exists for the NDF because it is a purely forward market. The hypothesis of no Granger causality from the onshore spot rate to the offshore rate is soundly rejected ($\alpha < 0.0001$). As for the opposite direction, the null is rejected six out of 10 times ($\alpha < 0.05$). Hence we conclude that there is stronger causality running from the onshore to the offshore spot exchange rate.

****Tables 4 and 5 about here***

As for the causality between the forward exchange rates, the results for which are also shown in Table 4, we find bidirectional Granger causality between all corresponding market pairs, and this is true regardless of the number of lags injected into the estimating equations. The low means of the estimated speeds of adjustment, $|\alpha, \beta| < 0.072$, imply that in general any movements away from the long-term equilibria between the various market pairs are slow to correct. An estimate of 0.0718, for example, at the upper limit of the means, implies a 7.18% adjustment back to equilibrium over the short term of a given trading day.

Looking at the individual estimates of Table 5, there would seem to be a modestly more rapid return to equilibrium from the onshore spot market Granger-causing the offshore spot market, as the number of lags increases; none of the speeds of adjustment for the offshore spot causing the onshore spot, are statistically significant. And while one can cherry-pick several instances, such as the bidirectional causality between the NDF 12M and CNH 12M markets, where the speeds of adjustment tend to decline in absolute value as the number of lags increases, their mean estimates provide an adequate summary of their behavior.

5. Nonlinear Causality

We live in a complex world, one in which we might be able to readily identify A as being related to B, and still further when, for example, B commonly occurs nine months after A occurs we can assert with some confidence that A has caused B. When dealing with economic phenomena in our complex and uncertain world of error-prone observations, however, we commonly can only *speculate* as to whether A is related to B, and what their precise relationship happens to be. While in the specific context of *Granger* causality any such relationship is implicitly and quite usefully *assumed* to be linear, the result of the assumption may well be to mask some important nonlinear connections between the two or fail to acknowledge and isolate other factors that impinge upon the relationship.

To broach the potential problems posed by the presence of nonlinearities that linear Granger causality assumes out of existence, we apply the *nonlinear* Granger causality approach to the residuals obtained from the linear causality model of Eq. (2). A general test for nonlinear Granger causality is developed by Baek and Brock (1992) as later modified by Hiemstra and Jones (1994). Thereafter, there were many theoretical developments (see, for example, McCracken, 2007; Bai et al., 2010) and applications (see, for example, Rashid, 2007; Qiao, et al., 2009). Readers may refer to Hiemstra and Jones (1994) and Bai et al. (2010) for information about the *HJ* test statistic for nonlinear Granger causality and we do not discuss it here.

**** Table 6 about here***

In the interest of parsimony, Table 6 only reports the results of the test for a length of five lags. They show that there is no nonlinearity for CNH 3M to cause CNY 3M ($p = 0.18$) and there is weak ($\alpha \leq 0.05$) nonlinearity from CNH 1M to CNY 1M, NDF 6M to CNY 6M, NDF 12M to CNY 12M, and CNH 1M to NDF 1M. As to the rest, there exists strong ($\alpha \leq 0.01$) nonlinearity. Thus, we can conclude that, in general, there is a strong nonlinear bidirectional causal relationship between any pair of the daily exchange rates for the RMB forward markets. This in turn implies that the relationship between any pair of the daily exchange rates for the RMB forward markets is not as straightforward as Eqs. (1) and (2) presume it to be. Rather, there exist some nonlinear components of causality. It is, however, beyond the scope of *this* paper to attempt to identify these.

6. Sub-Period Analysis

We repeat our analysis for the individual sub-periods to answer the basic question motivating our paper: Are there any cointegrating relationships among the RMB markets, and/or is there Granger causality within the sub-periods and if so do they differ, since the behavior of the *exchange rates* may well differ in the sub-periods? We focus solely on any such differences.

By visual inspection of Figure 1, the exchange rates would appear to change one month before each of our breakpoints and their accordant announcements related to the widening of the band. A cogent explanation for this is the presence of "insiders" who might have advance knowledge of the imminent change, say a month ahead of time, and who trade on the information. Thus, to choose the sub-period observations for analysis, we delete those pertaining to one month before, and one month after, the announced breakpoint. We delete the month after as it may take some time for the effects of the announcement to manifest itself in the market. Figure 1 supports this approach.

**** Table 7 about here***

Table 7 shows that the mean in the first sub-period is the highest and those in the second and third sub-periods are about the same. By contrast, the standard deviation in the third sub-period is the smallest and those of the first and second sub-periods are about the same. The estimates of the average skewness are positive for all sub-periods, with that in the first sub-period the highest, followed by that in the third sub-period; the skewness in the second sub-period is the smallest. The averages of the max and min values are the highest for the first sub-period. The average of the max in the second sub-period, however, is larger than that in the third sub-period, while the average of the min in the second sub-period is smaller than that in the third sub-period. This is not surprising, because the average standard deviation in the second sub-period is three times larger than that in the third sub-period.

To further confirm our conjecture that the exchange rates may behave differently in the three sub-periods, we first examine the stationarity of the data, the results for which are reported in Tables 8.

**** Table 8 and 9 about here***

In essence, for sub-period 1 we can reject the unit-root hypothesis for all 14 exchange rates ($\alpha = 0.01$), we can reject it for about half of them in sub-period 2, and for only two in sub-period 3. The inference is that the exchange rates were most predictable in sub-period 1, less predictable in sub-period 2, and basically random in sub-period 3. Thus, we infer that the exchange rates were more deterministic in the past and have only recently become more random.

Our findings of cointegration in each sub-period, which are reported in Table 9, are also striking. Though the cointegration hypothesis is not rejected for all pairs of exchange rates,[3] the cointegration coefficients are close to unity in the first sub-period, with the maximum and minimum values of 1.1856 and 0.8976. Their values tend to diverge from unity in the second sub-period, and particularly to be less than unity. The divergence from unity is especially pronounced in the third sub-period where their maximum and minimum values are 2.2975 and 0.1752, respectively. This again implies that the exchange rates are more aligned in sub-period 1, less aligned in sub-period 2, and are more random in sub-period 3.

**** Table 10 about here***

We next investigate the causality relationship between any pair of the exchange rates in each sub-period, and report the results in Table 10. In general, there is greater causality in sub-period 1, less in sub-period 2, and much less in sub-period 3. In sub-period 1, we uncover linear causality between all pairs of exchange rates except between the CNY 1M and the CNH 1M, and CNY 3M only weakly Granger-causes the CNH 3M, with only lag 8 being marginally significant ($\alpha = 0.05$).

For the second sub-period, we find that there is no, or only weak causality, from CNYs to CNHs in which both CNY 3M and 6M do not Granger-cause their corresponding CNHs, while CNY 1M and CNY 12M weakly Granger-cause their corresponding CNHs. Moreover, we find that CNY 3M, 6M and 12M weakly Granger-cause their corresponding NDFs and, in general, the linear causality between NDFs and CNHs is weak. The linear causality in the third sub-period tends to be even weaker. For example, there exists reasonably strong linear causality from the offshore spot RMB to the onshore spot RMB (with 6 and 7 lags in the first and second sub-periods, respectively) and there exists very strong causality from the onshore spot RMB to the offshore spot RMB (with all lags highly significant for sub-periods 1 and 2). In sub-period 3, however, there is no evidence of Granger causality from the offshore spot RMB to the onshore spot RMB, while there exists only weak causality from the onshore spot RMB to the offshore spot RMB (with only 4 lags weakly significant at $\alpha = 0.05$). The remaining relationships are similarly inferred from the table, and we defer to the interested reader to draw those inferences.

[3] Though all pairs of exchange rates are not rejected to be "cointegrated" in sub-period 1, we cannot call them cointegrated because the stationarity hypothesis is not rejected for all series.

**** Table 12 about here***

Applying the nonlinear causality test yields the results reported in Table 12. Those for the first sub-period show that, as is the case for the entire period, there is in general a strong bidirectional nonlinear causal relationship between any pair of the daily exchange rates, which implies that the relationship between any pair of the markets is more complicated than is implied by Eqs. (1) and (2).

The results for the other two sub-periods, however, differ from those of sub-period 1 and the entire period in that we detect nonlinear causality in only a few select cases. Thus we conclude that it is rare to observe nonlinear causality, at least in regard to the behavior of the exchange-rate markets.

Finally, since we cannot reject the stationarity hypothesis for all series in the first sub-period, it is appropriate to apply Eq. (3) to the data for that sub-period:

$$\begin{aligned} Y_t &= \alpha_0 + \sum_{i=1}^{n} \alpha_{1i} Y_{t-i} + \sum_{j=1}^{m} \alpha_{2j} X_{t-j} + u_{1t}, \\ X_t &= \beta_0 + \sum_{i=1}^{n} \beta_{1i} X_{t-i} + \sum_{j=1}^{m} \beta_{2j} Y_{t-j} + u_{2t}, \end{aligned} \tag{3}$$

The results strongly reject the null of no Granger causality between the market pairs, as all exhibit *p*-values that are less than 0.0001.

The procedure of the previous section is next applied to the residuals from Eq. (3), to test for nonlinear Granger causality in the sub-periods. We limit ourselves to only presenting the results for lag = 5, in Table 13. The nonlinear Granger-causality test reported in the table for sub-period 1 indicates that basically there exists bidirectional nonlinear information transmission between the spot exchange rates in the onshore market (SPOTon) and the offshore CNH market (SPOToff). Moreover, there is a bidirectional nonlinear information transmission between CNY (NDF) and CNH, inferred from the fact that nearly all the test statistics are significant, except for NDF 6M to CNY6M.

**** Table 13 about here ***

7. Forecasting

We now use the post-break-point data to see how well the causality model performs as a vehicle for forecasting. To do so, we employ a one-step-ahead forecast approach and compute both the mean absolute error (MAE) and the root mean squared error (RMSE) of the forecasts. We use the data y_t with t = 1 to T to get the first one-step-ahead forecast $f_{T+1} = \hat{y}_{T+1}$ and get the first one-step-ahead forecast error, $e_{T+1} = y_{T+1} - f_{T+1}$. Thereafter, we use the data y_t with t = 2 to T+1 to get the second one-step-ahead forecast $f_{T+2} = \hat{y}_{T+2}$ and obtain the second one-step-ahead forecast error $e_{T+2} = y_{T+2} - f_{T+1}$ and so on, so that we obtain $f_{T+1}, \ldots, f_{T+n}$. The mean absolute error (MAE) of the one-step-ahead forecasts is then computed by using

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_{T+i} - f_{T+i}| \quad (4)$$

and the root mean squared error (RMSE) of the one-step-ahead forecasts is then obtained by using

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_{T+i} - f_{T+i})^2}{n}} \ . \quad (5)$$

Since the conclusion drawn from using MAE for the one-step-ahead forecasts is the same as that from using RMSE, we only exhibit the MAE results in Table 14 for sub-periods 1, 2, and 3, respectively.[4]

**** Table 14 about here.

For sub-period 1, we use data from September 8, 2010 to January 31, 2012 as our first estimation subsample to forecast for February 2012 as our first forecasting subsample. From Table 14A, the smallest MAE for testing whether there is any linear causality from SPOTon to SPOToff is 0.004893, which supports the hypothesis that there is causality from the onshore spot rate to the offshore rate. As for the opposite direction, the smallest MAE for testing whether there is any linear causality from SPOToff to SPOTon is 0.003882, which supports the hypothesis that there is causality from the SPOToff to the SPOTon. For the causality between the forward exchange rates, the 12 pairs of smallest MAEs suggest that there is bidirectional Granger causality between corresponding market pairs. Only three of them suggest there is no causality relationship between pairs.

[4] The results from using RMSE are available on request.

For sub-period 2, we use data from May 14, 2012 to December 31, 2013 as our estimation subsample to forecast for January 2014. From Table 14B we see that the smallest MAE is 0.003822, in support of the inference that there is causality from the onshore spot rate to the offshore rate. For the causality between forward exchange rates we see that four out of the 12 pairs of smallest MAEs suggest that there is bidirectional Granger causality between corresponding market pairs. Only two of them suggest that there is no causal relationship.

The sub-period 3 forecasts for January 2015 use data from April 17, 2014 to December 31, 2014, and these MAEs are presented in Table 14C, the smallest of which is 0.010384, suggesting that there is causality from the onshore spot rate to the offshore rate. For the opposite direction, the smallest MAE for testing, and then inferring causality from SPOToff to SPOTon is 0.005875. Six out of the 12 pairs of smallest MAEs for the forward exchange rates suggest bidirectional Granger causality between corresponding market pairs. None of them suggest the absence of causality between any pair, and the inferences drawn from the results of the three tables are generally consistent with those previously drawn from Table 4.

We find that forecasting in sub-period 1 supports the hypothesis that there is bidirectional Granger causality from the onshore spot rate to the offshore rate and supports the hypothesis that there is bidirectional Granger causality between corresponding market pairs of the forward exchange rates. Forecasting in sub-period 2 supports the hypothesis that there is causality from the onshore spot rate to the offshore rate and that there is bidirectional Granger causality between corresponding market pairs. In addition, forecasting in sub-period 3 supports the hypothesis that there is bidirectional Granger causality from the onshore spot rate to the offshore rate and that there is bidirectional Granger causality between corresponding market pairs of the forward exchange rates.

In general, the results from the out-of-sample forecasts provide greater support for those of the in-sample estimation for the first sub-period when the time series are stationary than for the subsequent sub-periods when they are not. This would suggest that time-series-based forecasts are more reliable when the series are stationary than when they are not, a suggestion that would seem to make uncommonly good sense.

8. Discussion

With breakpoints coinciding with both recent times at which the foreign-exchange band widened, we found significant differences between the resultant three sub-periods, thus implying that this policy shift has had a material impact on the RMB markets. Firstly, stationarity tests indicated that the exchange rates were most predictable (in the sense that the inference from the out-of-sample forecasting is consistent with the inference from the in-sample estimation) in sub-period 1, less predictable in sub-period 2, and basically random in sub-period 3. This change is likely caused by the vagaries of market forces, as the exchange rates moved increasingly away from the central bank's predetermined rate and became more reflective of the market's demand and supply.

We also found that the causality relationships between the onshore and offshore exchange rates have weakened after each of the band-widening moves. This was revealed in tests for both linear and nonlinear causality. The weakening of the causality relationships suggests that the two exchange rates are increasingly in step with each other. This is consistent with what we would expect: the liberalization of foreign exchange controls should help close the gap between the onshore and offshore RMB markets. Due to the increase in the size of the permitted band of fluctuation, the resultant increase in exchange-rate flexibility has caused the offshore RMB to increasingly reflect the actions of foreign market participants whose views of the future direction of the currency could be diverging from the onshore rate that reflects the preferences of the central bank. Short-term capital flows are one source of this foreign participation. For instance, recent data has suggested that capital outflows from China are starting to accelerate as China's economy slows, and the RMB shows signs of no longer being a one-way bet (see Figure 2). This puts downward pressure on the RMB. The Chinese authorities, however, prefer the exchange-rate stability that mitigates disruption in financial markets and preserves investors' confidence in the currency. These forces pull the exchange rate in opposite directions and would be reflected in greater divergence between the onshore and offshore RMB levels with a semi-flexible currency.

**** Figure 2 about here ***

9. Conclusion

We have examined the impact of the Chinese government's liberalization policy on the RMB – in particular the widening of the RMB band – on the interconnectedness between the onshore and offshore RMB markets. Because such band-widening enhances exchange-rate flexibility, one would expect the onshore RMB exchange rate to better reflect market forces and hence fundamentally change the relationship between the onshore and offshore RMB markets.

We find that there was a change in the market dynamics of the RMB exchange rate after April 14, 2012 when the exchange-rate band was widened from 0.5% to 1%. This widening afforded greater exchange-rate flexibility, gave market forces a freer rein to determine exchange-rate movements, and created the first structural breakpoint in the long-term cointegration between the various RMB markets. The other breakpoint was on March 15, 2014 when the band widened from 1% to 2%. We find that there is a long-term equilibrium relationship between any pair of onshore and offshore spot and forward markets.

Our causality results indicate stronger causality from the onshore spot market to its offshore counterpart, but more balanced bidirectional causality in the forward market. This suggests an informational edge for the domestic market that lasts only in the very short term, probably because of the proximity to local events such as central bank moves, policy changes, and data releases. In the longer term, factors such as economic fundamentals would be relatively dominant, and news regarding these could emanate from China or its export markets globally.

The magnitude of exchange-rate movements is also found to be generally larger in the onshore market. Less-rapid information flow domestically could have caused traders to rely more on price movements or rumors, which in turn leads to greater trend-following and hence overshooting. Cultural factors of domestic participants could have also been at work, as was found in the Chinese stock market by Cai et al. (2007). A higher discount rate onshore, for instance, would attach greater importance to shorter-term factors and hence result in greater volatility, since these factors are more uncertain. Greater weight on more stable long-term factors such as economic fundamentals would have generated more modest exchange-rate fluctuations. In any event, as indicated by the low absolute estimates of the speeds of adjustment, the return to long-term equilibrium from any short-term departures from that equilibrium for any pair of the integrated RMB markets, would tend to be a very slow process, indeed.

Appendix 1: The background of the Chinese currency markets

The non-deliverable forward (NDF) market is an over-the-counter market developed for emerging markets with capital controls whose currencies cannot be delivered offshore. The NDF market is cash-settled in US$ and, as its name implies, does not involve delivery of the underlying currency. Given the lack of full convertibility, traditionally all offshore currency transactions involving the RMB were conducted in this NDF market. Hence, the RMB was previously centered on two markets: (1) an onshore market that was tightly controlled by the Chinese authorities; and (2) an offshore market based on the NDF market.

Starting in 2007, mainland financial institutions were, subject to approval, allowed to issue RMB-denominated bonds in Hong Kong. This was the first step towards creating investment outlets for the RMB in the territory. The scope for eligible issuers was subsequently expanded. In January 2009, China's central bank and the Hong Kong Monetary Authority signed a currency-swap agreement to provide liquidity of up to 200 billion RMB, subject to a renewable three-year term. Shortly thereafter, in June 2009, China launched the pilot scheme for RMB settlement of cross-border trade between Hong Kong and five Chinese cities, including Shanghai and four others in Guangdong province. In this scheme, RMB conversion between the onshore and offshore markets for trade-related transactions was allowed for the first time. Promoting the use of the RMB as a trade-settlement currency is a priority for China, since this reduces the currency risk faced by importers and exporters. Trade-settlement flows have since increased rapidly, as shown in Fig. A1. This growth trend of RMB deposits is widely expected to persist, as China continues to liberalize its exchange rate and establish the RMB as an international reserve currency.

**** Figures A1 and A2 about here ***

In 2010, the Hong Kong Monetary Authority announced that it would permit the RMB to be transferred between accounts in Hong Kong, regardless of purpose. This was a truly significant change, since unlike the NDF market, which is settled in US$, such currency transactions could now be directly settled in RMB. The market then took off and expanded rapidly. As seen in Fig.

A2, save for a dip in early 2012, RMB deposits in Hong Kong have enjoyed steady growth in the ensuing months. Based on the International Organization for Standardization's ISO 4217 code, the RMB is assigned the acronym CNH offshore, as compared to CNY for the onshore market.

References

Bai, Zhidong, Wing-Keung Wong and Bingzhi Zhang (2010). Multivariate Linear and Non-Linear Causality Tests, *Mathematics and Computers in Simulation*, 81, 5–17.

Cadarajat, Yarat, and Lubis, Alexander (2012). Offshore and onshore IDR Market: evidence on information spillover. *Bulletin of Monetary Economics and Banking*, 14(4), 323-347.

Cai, Bill, Charlie Cai and Kevin Keasey (2007). Influence of cultural factors on price clustering and price resistance in China's stock markets. *Accounting and Finance*, 47, 623–641.

Chiang, Thomas C., Zhuo Qiao, and Wing-Keung Wong (2010). New evidence on the relation between return volatility and trading volume. *Journal of Forecasting,* 29(5), 502–515.

Colavecchio, Roberts, and Funke, Michael (2008). Volatility transmissions between renminbi and Asia-Pacific on-shore and off-shore U.S. dollar futures. *China Economic Review*, *19*(4), 635-648.

Colavecchio, Roberts, and Funke, Michael (2009). Volatility dependence across Asia-Pacific onshore and offshore currency forwards markets. *Journal of Asian Economics,* 20(2), 174–196.

Ding, David K., Tse, Yiuman, and Williams, Michael R. (2013). The price discovery puzzle in offshore yuan trading: Different contributions for different contracts. *Journal of Futures Markets*, *34*(2), 103-123.

Engle, Robert F., and Granger, Clyve W. J. (1987). Cointegration and error correction: representation, estimation and testing. *Econometrica, 55*(2), 251-276.

Fung, Hung-Gay, Leung, Wai K., and Zhu, Jiang (2004). Nondeliverable forward market for Chinese RMB: A first look. *China Economic Review*, *15*(3), 348−352.

Granger, Clive W.J., Huang, Bwo-Nung. and Yang, Chin-Wei (2000). A bivariate causality between stock prices and exchange rates: evidence from recent Asian flu. *The Quarterly Review of Economics and Finance, 40*(3), 337-354.

Gu, Li, and McNellis, Paul D. (2012). Yen/Dollar volatility and Chinese fear of floating: Pressures from the NDF market. *Pacific-Basin Finance Journal*, *22*, 37-49.

Hiemstra, C. and Jones, J.D. (1994). Testing for linear and nonlinear Granger causality in the stock price–volume relation. *Journal of Finance*, 49, 1639–1664.

Jeon, Bang Nam, and Seo, Beongseon (2003). The impact of the Asian financial crisis on foreign exchange market efficiency: The case of East Asian countries. *Pacific-Basin Finance Journal*, *11*(4), 509-525.

Johansen, Søren (1991). Estimation and hypothesis testing of cointegration vectors in Gaussian autoregressive models. *Econometrica*, 5(6), 1551-1580.

Liu, Li-Gang, and Pauwels, Laurent L. (2012). Do external political pressures affect the Renminbi exchange rate? *Journal of International Money and Finance*, *31*(6), 1800-1818.

McCracken, Michael W. (2007). Asymptotics for out of sample tests of Granger causality. *Journal of Econometrics*, 140(2), 719–752.

Ouyang, Alice Y., Rajan, Rankishen S., and Willett, Thomas D. (2010). China as a reserve sink: The evidence from offset and sterilization coefficients. *Journal of International Money and Finance 29*(5), 951-972.

Park, Jinwoo (2001). Information flows between non-deliverable forward (NDF) and spot markets: Evidence from Korean currency. *Pacific-Basin Finance Journal*, *9*(4), 363-377.

Park, Daekeum, and Rhee, Changyong (2001). Measuring the degree of currency misalignment using offshore forward exchange rates: The case of the Korean financial crisis. *Journal of Asset Management*, *2*(1), 84-95.

Peng, Wensheng, Shu, Chang, and Yip, Raymond (2007). Renminbi derivatives: Recent development and issues. *China and World Economy*, *15*(5), 1–17.

Perron, Pierre (1989). The great crash, the oil price shock, and the unit root hypothesis. *Econometrica*, *57*(6), 1361-1401.

Qiao, Zhuo, McAleer, Michael, and Wong, Wing Keung (2009). Linear and nonlinear causality of consumption growth and consumer attitudes, *Economics Letters*, 102(3), 161-164.

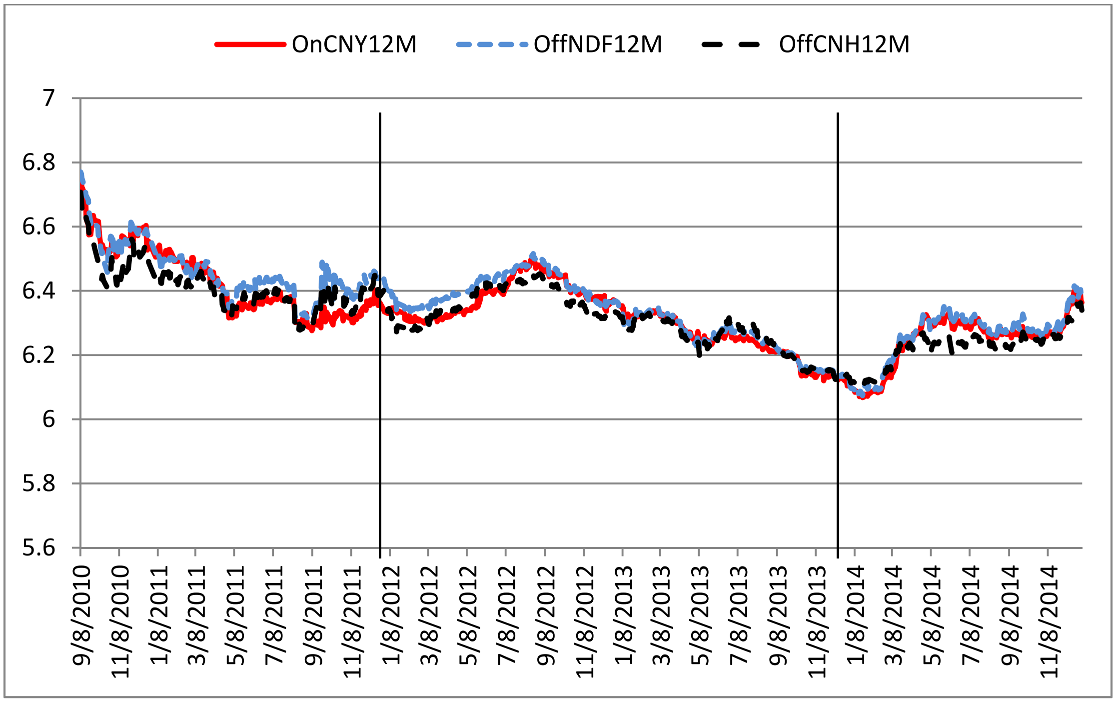
Rashid, Abdul, (2007). Stock prices and trading volume: An assessment for linear and nonlinear Granger causality. *Journal of Asian Economics*, 18(4), 595-612.

Sargan, John D. (1964). Wages and prices in the United Kingdom: A study in Econometric methodology. In Peter E. Hart, Gordon Mills, and John K. Whittaker (eds) *Econometric Analysis for National Economic Planning*. London: Butterworths, 25-54.

Tian, Lei, and Chen, Langnan (2013). A reinvestigation of the new RMB exchange rate regime. *China Economic Review*, *24*(1), 16-25.

Yang, Jian, and Leatham, David J. (2001). Currency convertibility and linkage between Chinese official and swap market exchange rates. *Contemporary Economic Policy*, *19*(3), 347–35.

Figure 1: Time-series plots of the daily exchange rates of the 12-month futures of CNY, NDF, and CNH



Note: OnCNY12M, OffNDF12M, OffCNH12M denote the 12-month futures of the Chinese RMB CNY, NDF, and CNH markets, respectively.

Figure 2: Changes to Trends: Capital Outflows and Weakening RMB

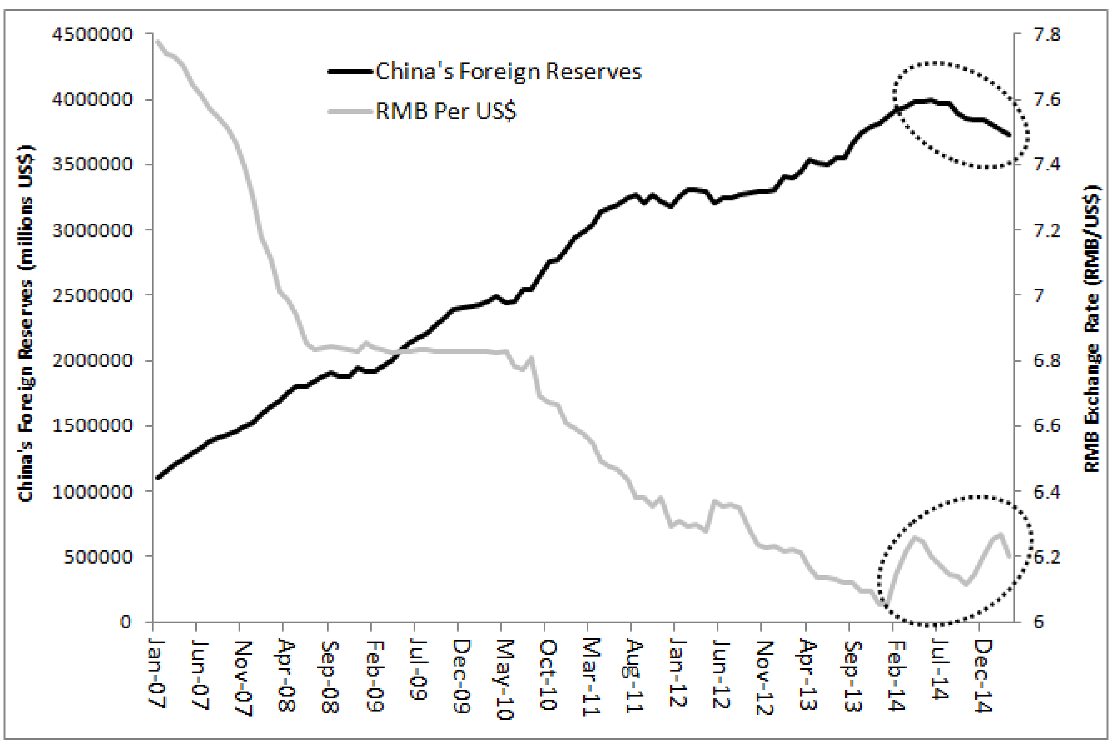


Table 1

Summary statistics for the daily exchange rates of the Chinese RMB: onshore (CNY), offshore (CNH), and offshore non-deliverable forward markets (NDF).

Variable	Mean	SD	Skewness	Kurtosis	Max	Min	Jarque Bera
OnRMB	6.2941	0.1688	0.7583***	-0.2091	6.7942	6.0406	100.00***
OffRMB	6.2900	0.1647	0.6049***	-0.4676***	6.7750	6.0196	71.77***
OnCNY1M	6.3017	0.1636	0.7371***	-0.1608	6.8000	6.0443	93.82***
OnCNY3M	6.3151	0.1484	0.6158***	-0.0438	6.7900	6.0553	64.81***
OnCNY6M	6.3165	0.1322	0.4989***	0.1496	6.7800	6.0596	43.43***
OnCNY12M	6.3292	0.1161	0.3210***	0.5369***	6.7400	6.0678	29.88***
OffNDF1M	6.2981	0.1603	0.5594***	-0.4472***	6.7800	6.0270	61.93***
OffNDF3M	6.3122	0.1519	0.4696***	-0.3750**	6.7800	6.0362	43.64***
OffNDF6M	6.3281	0.1393	0.3308***	-0.2016	6.7800	6.0496	20.40***
OffNDF12M	6.3514	0.1179	0.0658	0.2431	6.7700	6.0741	3.26
OffCNH1M	6.3036	0.1557	0.8408***	-0.0464	6.7934	6.0900	120.74***
OffCNH3M	6.3063	0.1424	0.7353***	-0.0804	6.7744	6.0890	92.54***
OffCNH6M	6.3089	0.1263	0.5817***	-0.0454	6.7453	6.0915	57.83***
OffCNH12M	6.3161	0.1016	0.2026***	0.1573	6.7075	6.0967	8.06***
Average	6.3122	0.1421	0.5230	-0.0707	6.7721	6.0601	58.01

Note: *, **, and *** denote the significance at the $\alpha = 0.10$, 0.05, and 0.01 levels, respectively; the total number of observations for each series was 1024.

Table 2 Unit-root tests for the levels and differences of CNY, CNH, and NDF.

Variable	Entire period	
Perron Unit-Root Test	level	difference
Onshore RMB	-2.6617	-33.2448***
Offshore RMB	-2.895	-35.0442***
Onshore CNY 1M	-2.7151	-40.8016***
Onshore CNY 3M	-3.1863*	-57.2152***
Onshore CNY 6M	-2.9695	-39.7752***
Onshore CNY 12M	-2.6914	-36.7136***
Offshore CNH 1M	-2.9063	-35.5159***
Offshore CNH 3M	-2.8661	-35.6163***
Offshore CNH 6M	-2.8897	-36.4277***
Offshore CNH 12M	-2.9781	-36.031***
Offshore NDF 1M	-3.0652	-32.4482***
Offshore NDF 3M	-3.1638	-31.4598***
Offshore NDF 6M	-3.2257*	-31.968***
Offshore NDF12M	-3.3779*	-30.2634***

Note: The entire period data have two structural breaks on April 14, 2012 and Mar 15, 2014.

Table 3 The results of the cointegration tests

Variable	Entire period			
Y_t with X_t	ADF	Adj. R^2	$\hat{\delta}_3$	p-value
Onshore RMB with Offshore RMB	-5.4218***	0.9852	1.02166	0.0007
CNY 1M with CNH 1M	-3.2554	0.9757	1.06754	<.0001
CNY 3M with CNH 3M	-6.3967***	0.9707	1.09041	<.0001
CNY 6M with CNH 6M	-5.6926***	0.9712	1.09897	<.0001
CNY 12M with CNH 12M	-4.4827***	0.9146	1.14046	<.0001
CNY 1M with NDF 1M	-5.3029***	0.9837	1.01787	0.006
CNY 3M with NDF 3M	-6.6249***	0.9728	0.99466	0.4862
CNY 6M with NDF 6M	-5.7424***	0.9781	0.97701	0.0002
CNY 12M with NDF 12M	-4.7068***	0.9480	1.01243	0.1466
CNH 1M with NDF 1M	-3.1175	0.9620	0.89418	<.0001
CNH 3M with NDF 3M	-3.7545**	0.9745	0.88116	<.0001
CNH 6M with NDF 6M	-4.9274***	0.9807	0.86523	<.0001
CNH 12M with NDF 12M	-5.8291***	0.9756	0.85106	<.0001

Table 4 Granger-causality results for the entire period, with two breakpoints

Null Hypothesis	Mean of Speeds of Adjustment	Number of times null rejected
SPOToff not Cause SPOTon	0.0055	6
SPOTon not Cause SPOToff	0.0718	10
CNH 1M not Cause CNY 1M	-0.0038	9
CNY 1M not Cause CNH 1M	0.0474	10
CNH 3M not Cause CNY 3M	-0.0148	10
CNY 3M not Cause CNH 3M	0.0440	10
CNH 6M not Cause CNY 6M	-0.0325	10
CNY 6M not Cause CNH 6M	0.0269	7
CNH 12M not Cause CNY12M	-0.0354	10
CNY 12M not Cause CNH12M	0.0102	10
NDF 1M not Cause CNY 1M	0.0010	10
CNY 1M not Cause NDF 1M	0.0351	10
NDF 3M not Cause CNY 3M	-0.0066	10
CNY 3M not Cause NDF 3M	0.0606	10
NDF 6M not Cause CNY 6M	-0.0281	10
CNY 6M not Cause NDF 6M	0.0482	10
NDF 12M not Cause CNY 12M	-0.0238	10
CNY 12M not Cause NDF 12M	0.0207	9
NDF 1M not Cause CNH 1M	-0.0209	10
CNH 1M not Cause NDF 1M	0.0025	0
NDF 3M not Cause CNH 3M	-0.0234	10
CNH 3M not Cause NDF 3M	0.0131	6
NDF 6M not Cause CNH 6M	-0.0242	10
CNH 6M not Cause NDF 6M	0.0362	10
NDF 12M not Cause CNH 12M	-0.0132	10
CNH 12M not Cause NDF 12M	0.0724	10

Table 5 Estimates of the Speeds of Adjustment for the entire period, with two breakpoints

1	2	3	4	5	6	7	8	9	10
0.0018	0.0037	0.0041	0.0049	0.0072	0.0023	0.0041	0.0082	0.0101	0.0083
0.0597***	0.0631***	0.0627***	0.0617***	0.0706***	0.0665***	0.0724***	0.0835***	0.0843***	0.0931***
-0.0053	-0.0034	-0.004	-0.003	-0.0008	-0.0033	-0.0038	-0.0038	-0.0049	-0.0057
0.0510***	0.0495***	0.0474***	0.0459***	0.0492***	0.0432***	0.0465***	0.0495***	0.0463***	0.0456***
-0.0167*	-0.0158*	-0.0146	-0.0149	-0.0116	-0.0139	-0.0134	-0.0145	-0.016	-0.0173*
0.0467***	0.0442***	0.0434***	0.0406***	0.0443***	0.0406***	0.0442***	0.0473***	0.0456***	0.0435***
-0.0377***	-0.0326***	-0.0340***	-0.0332***	-0.0282**	-0.0298***	-0.0315***	-0.0306***	-0.0328***	-0.0346***
0.0305**	0.0291**	0.0267*	0.0218	0.0271*	0.0235	0.0268*	0.0294*	0.0286*	0.0260*
-0.0408***	-0.0397***	-0.0350***	-0.0360***	-0.0330***	-0.0335***	-0.0327***	-0.0327***	-0.0349***	-0.0353***
0.0138	0.0127	0.0091	0.0043	0.0095	0.0067	0.0106	0.0132	0.0118	0.0105
-0.0055	-0.0031	0.0007	0.0019	0.0016	0.0033	0.0015	0.003	0.0034	0.0028
0.0389***	0.0356***	0.0348***	0.0348***	0.0345***	0.0342***	0.0329***	0.0348***	0.0347***	0.0357***
-0.0162	-0.0141	-0.0075	-0.007	-0.0043	-0.0027	-0.003	-0.0043	-0.0032	-0.0035
0.0648***	0.0593***	0.0622***	0.0579***	0.0588***	0.0583***	0.0590***	0.0612***	0.0616***	0.0634***
-0.0369***	-0.0349***	-0.0320***	-0.0298**	-0.0259**	-0.0250**	-0.0232*	-0.0243*	-0.0246*	-0.0241*
0.0532***	0.0483***	0.0488***	0.0434***	0.0437***	0.0441***	0.0462***	0.0511***	0.0493***	0.0541***
-0.0262***	-0.0292***	-0.0255***	-0.0236***	-0.0225***	-0.0228***	-0.0224**	-0.0206**	-0.0230***	-0.0227**
0.0260**	0.0208*	0.0194*	0.0159	0.0166	0.0185	0.0198*	0.0241**	0.0222*	0.0239**
-0.0222**	-0.0216**	-0.0210**	-0.0207**	-0.0223**	-0.0192*	-0.0210**	-0.0213**	-0.0201**	-0.0194*
0.0012	0.0008	0.0019	0.0017	0.0013	0.0032	0.0026	0.0035	0.0047	0.0041
-0.0301**	-0.0259*	-0.0248*	-0.0242*	-0.0246*	-0.0214	-0.0233*	-0.0215	-0.0198	-0.0185
0.0129	0.0107	0.0127	0.0112	0.0115	0.0141	0.0137	0.0138	0.0156	0.0147
-0.0379**	-0.0341*	-0.0289	-0.027	-0.0258	-0.0216	-0.0224	-0.0166	-0.0164	-0.0117
0.0419**	0.0342*	0.0367*	0.0339*	0.0314*	0.0332*	0.0330*	0.0386**	0.0386**	0.0402**
-0.0298	-0.026	-0.0199	-0.0216	-0.0178	-0.0121	-0.0099	-0.0001	0.001	0.0039
0.0903***	0.0725***	0.0718***	0.0659***	0.0640***	0.0674***	0.0674***	0.0737***	0.0743***	0.0765***

Note: The *, **, and *** denote the significance at 10%, 5% and 1% levels, respectively. The upper value in each cell indicates the result of the α in equation (2), while the lower indicates the results of the β in equation (2). The Null Hypothesis is same as Table 4, we skip to report it in this table.

Table 6 Nonlinear causality tests for the entire period

Null Hypothesis	Entire period	
	HJ Statistic	P-value
SPOToff not Cause SPOTon	3.492697	0.000239***
SPOTon not Cause SPOToff	3.875297	0.000053***
CNH 1M not Cause CNY 1M	1.659371	0.04852**
CNY 1M not Cause CNH 1M	3.825194	0.000065***
CNH 3M not Cause CNY 3M	-0.906163	0.182425
CNY 3M not Cause CNH 3M	2.646217	0.00407***
CNH 6M not Cause CNY 6M	3.480684	0.00025***
CNY 6M not Cause CNH 6M	3.149578	0.000818***
CNH 12M not Cause CNY 12M	3.089979	0.001001***
CNY 12M not Cause CNH 12M	4.427114	0.000005***
NDF 1M not Cause CNY 1M	3.587289	0.000167***
CNY 1M not Cause NDF 1M	3.227917	0.000623***
NDF 3M not Cause CNY 3M	3.297368	0.000488***
CNY 3M not Cause NDF 3M	3.61132	0.000152***
NDF 6M not Cause CNY 6M	2.040096	0.02067**
CNY 6M not Cause NDF 6M	3.047809	0.001153***
NDF 12M not Cause CNY 12M	1.748288	0.040207**
CNY 12M not Cause NDF 12M	3.818514	0.000067***
NDF 1M not Cause CNH 1M	3.573358	0.000176***
CNH 1M not Cause NDF 1M	1.737184	0.041177**
NDF 3M not Cause CNH 3M	3.9735	0.000035***
CNH 3M not Cause NDF 3M	2.41371	0.007896***
NDF 6M not Cause CNH 6M	4.222841	0.000012***
CNH 6M not Cause NDF 6M	4.143677	0.000017***
NDF 12M not Cause CNH 12M	4.266055	0.00001***
CNH 12M not Cause NDF 12M	4.415645	0.000005***

Note: The *, **, and *** denote the significance at 10%, 5% and 1% levels, respectively. We report lag=5 as an example in this table.

Table 7 Summary statistics for the three sub-periods

A. Sub-period 1, from Sep 8, 2010 to Mar 13, 2012

Variable	Mean	SD	Skewness	Kurtosis	Max	Min	Jarque Bera
OnRMB	6.4813	0.1289	0.2762**	-1.0905***	6.7942	6.2938	21.36***
OffRMB	6.4741	0.1147	0.1797	-0.7707***	6.775	6.275	10.33***
OnCNY1M	6.4805	0.1263	0.3212**	-1.0479***	6.8	6.3002	21.59***
OnCNY3M	6.4683	0.1182	0.4029***	-0.8693***	6.79	6.303	20.08***
OnCNY6M	6.4424	0.1068	0.6578***	-0.2882	6.78	6.302	25.93***
OnCNY12M	6.4104	0.1056	0.8815***	-0.1622	6.74	6.276	44.79***
OffNDF1M	6.4749	0.1115	0.2369*	-0.6886***	6.78	6.2915	9.98***
OffNDF3M	6.474	0.1062	0.3680***	-0.4799*	6.78	6.3023	11.04***
OffNDF6M	6.4671	0.0988	0.5920***	0.0058	6.78	6.312	20.03***
OffNDF12M	6.4464	0.0872	1.0285***	1.3358***	6.77	6.311	85.98***
OffCNH1M	6.4747	0.1252	0.2972**	-1.0163***	6.7934	6.289	19.81***
OffCNH3M	6.4583	0.113	0.3740***	-0.7133***	6.7744	6.2795	15.27***
OffCNH6M	6.4356	0.1	0.5062***	-0.1432	6.7453	6.2705	14.94***
OffCNH12M	6.395	0.0802	0.8380***	1.4909***	6.7075	6.2575	71.91***
Average	6.4526	0.1068	0.5386	-0.2226	6.7702	6.2911	29.96

B. Sub-period 2, from May 14, 2012 to Feb 17, 2014

Variable	Mean	SD	Skewness	Kurtosis	Max	Min	Jarque Bera
OnRMB	6.2012	0.1014	0.3314***	-1.1098***	6.3885	6.0406	29.73***
OffRMB	6.1966	0.1055	0.3384***	-1.0305***	6.389	6.0196	27.04***
OnCNY1M	6.2128	0.1023	0.2915**	-1.1033***	6.4045	6.0443	27.71***
OnCNY3M	6.2331	0.1048	0.1886	-1.1332***	6.425	6.0553	25.38***
OnCNY6M	6.255	0.1091	0.0418	-1.0999***	6.4479	6.0596	21.65***
OnCNY12M	6.2934	0.1167	-0.1837	-0.9772***	6.4975	6.0678	19.39***
OffNDF1M	6.2075	0.1077	0.2915**	-1.0575***	6.3977	6.027	25.94***
OffNDF3M	6.2286	0.1116	0.2004*	-1.0939***	6.418	6.0362	24.14***
OffNDF6M	6.2565	0.1154	0.0733	-1.0883***	6.4513	6.0496	21.45***
OffNDF12M	6.3046	0.1196	-0.0965	-1.0385***	6.5158	6.0741	19.85***
OffCNH1M	6.2384	0.0843	-0.1869	-1.4064***	6.3635	6.09	37.68***
OffCNH3M	6.2471	0.0888	-0.1555	-1.2922***	6.386	6.089	31.43***
OffCNH6M	6.2597	0.0931	-0.1572	-1.1784***	6.4065	6.0915	26.46***
OffCNH12M	6.2879	0.1008	-0.1845	-0.9944***	6.455	6.0967	20.02***
Average	6.2515	0.1045	0.0138	-1.1214	6.4303	6.0647	25.13

C. Sub-period 3, from April 17, 2014 to Dec 31, 2014

Variable	Mean	SD	Skewness	Kurtosis	Max	Min	Jarque Bera
OnRMB	6.1797	0.0455	0.1048	-1.4838***	6.2595	6.1114	16.37***
OffRMB	6.1832	0.043	0.1085	-1.4209***	6.2645	6.1143	15.06***
OnCNY1M	6.1966	0.0436	-0.0247	-1.5174***	6.2684	6.1255	16.81***
OnCNY3M	6.2446	0.0514	-0.0946	-1.2202***	6.3464	6.156	11.12***
OnCNY6M	6.2499	0.0353	0.3335*	-0.8397**	6.3349	6.195	8.39**
OnCNY12M	6.2897	0.0338	1.3457***	1.5337***	6.3986	6.248	69.97***
OffNDF1M	6.1985	0.0418	0.0308	-1.4691***	6.2755	6.1274	15.77***
OffNDF3M	6.2248	0.0393	0.0591	-1.3809***	6.2995	6.1568	14.01***
OffNDF6M	6.2566	0.0364	0.3786**	-0.7881**	6.3458	6.196	8.71**
OffNDF12M	6.3052	0.0338	1.2890***	1.4080***	6.4153	6.2605	62.92***
OffCNH1M	6.1612	0.0142	-0.2413	-0.8020**	6.1872	6.126	6.39**
OffCNH3M	6.182	0.0157	0.0786	-0.9545***	6.214	6.1475	6.82**
OffCNH6M	6.207	0.0203	0.9926***	0.7550**	6.2665	6.1745	32.89***
OffCNH12M	6.2532	0.0322	1.8846***	3.6867***	6.363	6.205	202.70***
Average	6.2237	0.0347	0.4461	-0.3209	6.3028	6.1674	34.85

Table 8 Unit-root tests for the three sub-periods

Variable	Sub-period 1		Sub-period 2		Sub-period 3	
Perron Unit-Root Test	level	difference	level	difference	level	difference
Onshore RMB	-4.362***	-20.2295***	-2.3916	-20.4412***	-0.2531	-13.9595***
Offshore RMB	-4.5637***	-21.1407***	-2.7283	-20.1762***	-0.7184	-14.3241***
Onshore CNY 1M	-4.8581***	-23.1057***	-2.8827	-23.6677***	-0.7767	-17.3727***
Onshore CNY 3M	-5.4038***	-23.2476***	-4.0795***	-31.2324***	-6.3541***	-24.4714***
Onshore CNY 6M	-4.887***	-22.3921***	-4.1729***	-31.8927***	-0.8413	-13.3297***
Onshore CNY 12M	-3.4649**	-22.8233***	-3.9575**	-23.1809***	-1.1392	-12.6966***
Offshore CNH 1M	-4.6643***	-21.4863***	-2.8813	-21.3621***	-0.9289	-14.0566***
Offshore CNH 3M	-4.5826***	-21.5474***	-3.2655*	-21.9178***	-1.0525	-13.8869***
Offshore CNH 6M	-4.4889***	-22.2679***	-3.4413**	-21.7845***	-1.2691	-13.7631***
Offshore CNH 12M	-4.1533***	-21.7874***	-3.4103*	-22.5274***	-1.7381	-13.1001***
Offshore NDF 1M	-4.5665***	-19.4909***	-3.4993**	-19.1648***	-4.1866***	-11.7637***
Offshore NDF 3M	-4.6144***	-18.3764***	-3.7448**	-19.4706***	-2.3659	-12.9895***
Offshore NDF 6M	-4.4967***	-18.8145***	-3.6295**	-19.8589***	-1.942	-12.1426***
Offshore NDF12M	-4.4885***	-17.572***	-3.1696*	-19.9236***	-1.948	-11.7229***

Table 9 The results of the cointegration tests for the three sub-periods

Variable	Sub-period 1				Sub-period 2				Sub-period 3			
Y_t with X_t	ADF	Adj. R^2	$\hat{\delta}_3$	*p*-value	ADF	Adj. R^2	$\hat{\delta}_3$	*p*-value	ADF	Adj. R^2	$\hat{\delta}_3$	*p*-value
Onshore RMB with Offshore RMB	-3.6728**	0.9397	1.0896	<.0001	-3.9260**	0.9927	0.9574	<0.0001	-5.0757***	0.9797	1.0462	<.0001
CNY 1M with CNH 1M	-5.1901***	0.9916	1.0047	0.3515	-1.648	0.9382	1.1765	<0.0001	-1.1896	0.2411	1.5197	0.0112
CNY 3M with CNH 3M	-4.5788***	0.9724	1.0322	0.0007	-2.5111	0.962	1.1575	<0.0001	-5.1858***	0.4899	2.2975	<.0001
CNY 6M with CNH 6M	-3.8517**	0.939	1.0354	0.0136	-3.3471*	0.9693	1.1539	<0.0001	-4.0499***	0.6537	1.4104	<.0001
CNY 12M with CNH 12M	-3.2703*	0.8104	1.1856	<.0001	-2.796	0.9449	1.1255	<0.0001	-2.8043	0.6042	0.8181	0.0004
CNY 1M with NDF 1M	-3.5723**	0.9383	1.0972	<.0001	-4.6233***	0.9937	0.947	<0.0001	-4.8339***	0.9551	1.0215	0.203
CNY 3M with NDF 3M	-3.6691**	0.9403	1.0796	<.0001	-5.1155***	0.989	0.9339	<0.0001	-4.6469***	0.5524	0.9753	0.71
CNY 6M with NDF 6M	-3.6376**	0.9315	1.0438	0.0044	-4.5820***	0.9867	0.9394	<0.0001	-3.9306**	0.9487	0.9443	0.001
CNY 12M with NDF 12M	-3.8658**	0.878	1.1343	<.0001	-3.5037**	0.9768	0.9645	<0.0001	-3.8292**	0.9311	0.9663	0.0929
CNH 1M with NDF 1M	-4.1547***	0.9561	1.0978	<.0001	-1.5351	0.9317	0.7551	<0.0001	-2.7934	0.2601	0.1752	<.0001
CNH 3M with NDF 3M	-4.9823***	0.9739	1.0497	<.0001	-1.8576	0.9621	0.7806	<0.0001	-3.8904**	0.68	0.3303	<.0001
CNH 6M with NDF 6M	-6.1430***	0.9786	1.0013	0.8706	-2.2642	0.9795	0.7986	<0.0001	-4.2928***	0.7002	0.4663	<.0001
CNH 12M with NDF 12M	-4.7084***	0.953	0.8976	<.0001	-2.7985	0.9837	0.836	<0.0001	-4.8716***	0.6567	0.7735	<.0001

Note: $\hat{\delta}_3$ is the estimate of δ_3 in equation (1). ADF is the Augmented Dickey-Fuller test statistic for stationarity of the estimated residuals. All $\hat{\delta}_3$ are statistically significant at $\alpha = 0.01$. The column "*p*-value" reports the *p*-values of the statistic to test H_0: $\delta_3 = 1$.

Table 10 Granger-causality results for the three sub-periods

	Sub-period 1		Sub-period 2		Sub-period 3	
Null Hypothesis	Mean of Speeds of Adjustment	Number of times null rejected	Mean of Speeds of Adjustment	Number of times null rejected	Mean of Speeds of Adjustment	Number of times null rejected
SPOToff not Cause SPOTon	0.0112	6	0.0289	7	-0.0770	0
SPOTon not Cause SPOToff	0.0890	10	0.1477	10	0.2617	4
CNH 1M not Cause CNY 1M	-0.2092	10	0.0022	10	-0.0182	10
CNY 1M not Cause CNH 1M	0.1020	0	0.0214	4	0.0198	4
CNH 3M not Cause CNY 3M	-0.1168	10	-0.0186	10	-0.4428	10
CNY 3M not Cause CNH 3M	0.0857	1	0.0245	0	0.0412	0
CNH 6M not Cause CNY 6M	-0.0929	10	-0.0468	10	-0.0446	10
CNY 6M not Cause CNH 6M	0.0443	0	0.0224	0	0.0384	0
CNH 12M not Cause CNY12M	-0.0414	10	-0.0405	10	-0.0525	4
CNY 12M not Cause CNH12M	0.0281	0	0.0042	6	0.0049	5
NDF 1M not Cause CNY 1M	-0.0011	10	-0.0402	10	-0.2787	10
CNY 1M not Cause NDF 1M	0.0837	10	0.1292	10	0.1096	1
NDF 3M not Cause CNY 3M	-0.0351	10	-0.1589	10	-0.4962	10
CNY 3M not Cause NDF 3M	0.0892	10	0.0358	3	-0.0072	0
NDF 6M not Cause CNY 6M	-0.0723	10	-0.1519	10	-0.1442	10
CNY 6M not Cause NDF 6M	0.0672	10	0.0002	1	0.0854	0
NDF 12M not Cause CNY 12M	-0.0580	10	-0.0842	10	-0.0716	10
CNY 12M not Cause NDF 12M	0.0433	10	-0.0127	2	0.2323	7
NDF 1M not Cause CNH 1M	0.0437	10	-0.0175	8	-0.1142	10
CNH 1M not Cause NDF 1M	0.1085	10	-0.0074	5	-0.1618	0
NDF 3M not Cause CNH 3M	0.0499	8	-0.0225	3	-0.2152	8
CNH 3M not Cause NDF 3M	0.1768	10	-0.0079	6	-0.1395	0
NDF 6M not Cause CNH 6M	-0.0058	4	-0.0356	4	-0.1226	3
CNH 6M not Cause NDF 6M	0.2632	10	-0.0046	1	-0.0225	0
NDF 12M not Cause CNH 12M	-0.1499	10	-0.0343	10	0.0061	0
CNH 12M not Cause NDF 12M	0.0382	10	0.0313	2	0.0425	0

Notes: CNH, CNY, and NDF at different horizons from 1 month to 12 months, where the CNY, CNH and DNF stand for the RMB onshore, offshore and offshore non-deliverable forward markets, respectively. This table shows the Mean of Speeds of Adjustment and number of times the null of no Granger-causality between onshore and offshore RMB exchange rates is rejected with 5% level.

Table 11 Estimates of the Speeds of Adjustment for the three sub-periods

Sub-period 1				Sub-period 2				Sub-period 3			
1	2	3	4	1	2	3	4	1	2	3	4
0.0093	0.0117	0.0101	0.0128	0.0184	0.0193	0.0306	0.0275	-0.1405	-0.1593	-0.0771	-0.0947
0.0878***	0.0928***	0.0865***	0.0882***	0.1535***	0.1490***	0.1544***	0.1526***	0.3158**	0.2721*	0.3178**	0.2410
-0.2546***	-0.2585***	-0.2227***	-0.1995***	0.0040	0.0042	0.0058	0.0062	-0.0146	-0.0058	-0.0101	-0.0104
0.1204**	0.0924	0.0631	0.0737	0.0206**	0.0213**	0.0224**	0.0226**	0.0132	0.0151	0.0163*	0.0168*
-0.1425***	-0.1488***	-0.1339***	-0.1290***	-0.0317*	-0.0205	-0.0193	-0.0201	-0.5392***	-0.4934***	-0.4586***	-0.4368***
0.0892**	0.0645*	0.0604	0.0710*	0.0255*	0.0247*	0.0241*	0.0249*	0.0327**	0.0351*	0.0331*	0.0361*
-0.1079***	-0.1055***	-0.1027***	-0.0994***	-0.0538***	-0.0529***	-0.0537***	-0.0486**	-0.0519*	-0.0568*	-0.0396	-0.0466
0.0586*	0.0422	0.0337	0.0311	0.0230	0.0184	0.0185	0.0208	0.0456	0.0367	0.0433	0.0405
-0.0426**	-0.0435**	-0.0436**	-0.0403**	-0.0423***	-0.0433***	-0.0432***	-0.0409***	-0.0549*	-0.0539*	-0.0477	-0.0513
0.0376*	0.0306	0.0230	0.0205	0.0048	-0.0008	-0.0001	0.0015	0.0029	0.0054	0.0101	0.0086
-0.0052	0.0007	0.0064	0.0074	-0.0618*	-0.0638*	-0.0544	-0.0472	-0.4401***	-0.3505***	-0.2882***	-0.2823**
0.0793***	0.0824***	0.0864***	0.0799***	0.1471***	0.1210***	0.1242***	0.1272***	0.0792	0.1101	0.1358	0.0962
-0.0470*	-0.0325	-0.0277	-0.0284	-0.1972***	-0.1746***	-0.1849***	-0.1794***	-0.5895***	-0.5072***	-0.4827***	-0.4377***
0.0841***	0.0785**	0.0822***	0.0799**	0.0573*	0.0337	0.0296	0.0316	0.0165	0.0086	-0.0069	-0.0157
-0.0774**	-0.0683**	-0.0627**	-0.0654**	-0.1527***	-0.1575***	-0.1665***	-0.1632***	-0.1804**	-0.1786*	-0.1325	-0.1425
0.0727**	0.0620*	0.0637*	0.0556	0.0076	-0.0095	-0.0138	-0.0106	0.1254	0.0863	0.1108	0.0583
-0.0584**	-0.0518**	-0.0542**	-0.0558**	-0.0899***	-0.0884***	-0.0895***	-0.0885***	-0.1126	-0.1046	-0.0752	-0.0613
0.0487*	0.0471*	0.0458	0.0373	-0.0083	-0.0158	-0.0194	-0.0203	0.2317**	0.2087*	0.2166*	0.1969
0.0423*	0.0464**	0.0518**	0.0499**	-0.0172	-0.0199*	-0.0196*	-0.0191*	-0.0809***	-0.0820***	-0.0988***	-0.0959***
0.1054***	0.1140***	0.1269***	0.1139***	-0.0061	-0.0100	-0.0102	-0.0089	-0.1149*	-0.1161*	-0.1326**	-0.1341**
0.0411	0.0523	0.0644	0.0600	-0.0232	-0.0255*	-0.0267*	-0.0244	-0.1717***	-0.1713***	-0.2023***	-0.2016***
0.1746***	0.1831***	0.2065***	0.1852***	-0.0063	-0.0118	-0.0118	-0.0098	-0.0818	-0.0822	-0.1121	-0.1065
-0.0035	0.0107	0.0281	0.0284	-0.0414*	-0.0404*	-0.0396*	-0.0375	-0.1251**	-0.1057*	-0.1272**	-0.1209*
0.2819***	0.2808***	0.3120***	0.2916***	-0.0038	-0.0090	-0.0096	-0.0072	0.0016	0.0125	-0.0186	0.0025
-0.1593***	-0.1475**	-0.1206*	-0.1251*	-0.0384	-0.0279	-0.0315	-0.0305	-0.0070	-0.0004	-0.0093	0.0056
0.0996*	0.0845	0.0897	0.0645	0.0245	0.0273	0.0288	0.0319	0.0402	0.0409	0.0335	0.0455

Note: The *, **, and *** denote the significance at 10%, 5% and 1% levels, respectively. The upper value in each cell indicates the result of the α in equation (2), while the lower indicates the results of the β in equation (2). The Null Hypothesis is same as Table 10, we skip to report it in this table. We only report the results of the first 4 lags and skip reporting the results from lag 5 to lag 10 for simplicity.

Table 12 Nonlinear causality results for the three sub-periods

Null Hypothesis	Sub-period 1		Sub-period 2		Sub-period 3	
	HJ Statistic	P-value	HJ Statistic	P-value	HJ Statistic	P-value
SPOToff not Cause SPOTon	1.41049	0.079198*	2.27709	0.01139**	1.090311	0.137788
SPOTon not Cause SPOToff	3.159708	0.00079***	0.37789	0.352756	1.499001	0.066937**
CNH 1M not Cause CNY 1M	1.513461	0.065081*	0.936489	0.174511	-0.195756	0.422401
CNY 1M not Cause CNH 1M	3.548088	0.000194***	2.201722	0.013842	-0.495306	0.310192
CNH 3M not Cause CNY 3M	2.856531	0.002141***	-0.095596	0.461921	-1.522398	0.063955*
CNY 3M not Cause CNH 3M	3.312709	0.000462***	2.356077	0.009235***	-1.447884	0.073825*
CNH 6M not Cause CNY 6M	2.540893	0.005528***	-0.250011	0.401289	1.172733	0.120451
CNY 6M not Cause CNH 6M	2.789754	0.002637***	-0.264922	0.395535	0.32259	0.373503
CNH 12M not Cause CNY 12M	1.910219	0.028053**	0.305231	0.380095	0.054568	0.478241
CNY 12M not Cause CNH 12M	1.876116	0.03032**	-0.628174	0.264945	0.880973	0.189166
NDF 1M not Cause CNY 1M	2.054694	0.019954**	2.250845	0.012198**	0.387264	0.34928
CNY 1M not Cause NDF 1M	2.907112	0.001824***	2.245803	0.012358	0.632892	0.263402
NDF 3M not Cause CNY 3M	1.480755	0.069336*	2.415135	0.007865***	-2.839784	0.002257***
CNY 3M not Cause NDF 3M	3.009368	0.001309***	2.591637	0.004776***	-1.909179	0.028119**
NDF 6M not Cause CNY 6M	0.3469	0.364333	-0.106422	0.457624	1.223249	0.110618
CNY 6M not Cause NDF 6M	2.755296	0.002932***	0.438173	0.33063	1.96981	0.02443**
NDF 12M not Cause CNY 12M	0.926889	0.176992	0.700157	0.241915	-0.186687	0.425953
CNY 12M not Cause NDF 12M	1.468539	0.070979*	1.365356	0.086071*	1.598357	0.054982*
NDF 1M not Cause CNH 1M	2.527065	0.005751***	1.219909	0.11125	0.094459	0.462372
CNH 1M not Cause NDF 1M	2.343423	0.009554***	0.284757	0.387915	0.903107	0.183235
NDF 3M not Cause CNH 3M	2.391395	0.008392***	1.714116	0.043254**	0.538444	0.295135
CNH 3M not Cause NDF 3M	2.190202	0.014255**	-0.417546	0.33814	0.125321	0.450135
NDF 6M not Cause CNH 6M	1.823817	0.03409**	0.417607	0.338117	0.801962	0.211287
CNH 6M not Cause NDF 6M	2.905586	0.001833***	1.124359	0.13043	0.897921	0.184614
NDF 12M not Cause CNH 12M	1.732768	0.041568**	1.039462	0.149295	0.152333	0.439462
CNH 12M not Cause NDF 12M	2.39548	0.008299***	0.816665	0.20706	-0.12135	0.451707

Table 13 The Linear and Non-linear Granger-causality test for Sub-period 1

Null Hypothesis	Number of times null rejected	Nonlinear causality	
		HJ Statistic	P-value
SPOToff not Cause SPOTon	10	1.292079	0.098165*
SPOTon not Cause SPOToff	10	3.202565	0.000681***
CNH 1M not Cause CNY 1M	10	2.017956	0.021798**
CNY 1M not Cause CNH 1M	10	3.412427	0.000322***
CNH 3M not Cause CNY 3M	10	3.116184	0.000916***
CNY 3M not Cause CNH 3M	10	3.213572	0.000655***
CNH 6M not Cause CNY 6M	10	2.707032	0.003394***
CNY 6M not Cause CNH 6M	10	2.658915	0.00392***
CNH 12M not Cause CNY12M	10	2.356196	0.009232***
CNY 12M not Cause CNH12M	10	2.496223	0.006276***
NDF 1M not Cause CNY 1M	10	2.163885	0.015237**
CNY 1M not Cause NDF 1M	10	2.890733	0.001922***
NDF 3M not Cause CNY 3M	10	1.750888	0.039983**
CNY 3M not Cause NDF 3M	10	2.941823	0.001631***
NDF 6M not Cause CNY 6M	10	0.596292	0.27549
CNY 6M not Cause NDF 6M	10	2.628077	0.00429***
NDF 12M not Cause CNY 12M	10	0.325281	0.372484
CNY 12M not Cause NDF 12M	10	1.446541	0.074013*
NDF 1M not Cause CNH 1M	10	2.268229	0.011658**
CNH 1M not Cause NDF 1M	10	2.782559	0.002697***
NDF 3M not Cause CNH 3M	10	2.301609	0.010679**
CNH 3M not Cause NDF 3M	10	2.663271	0.003869***
NDF 6M not Cause CNH 6M	10	1.79169	0.036591**
CNH 6M not Cause NDF 6M	10	3.576594	0.000174***
NDF 12M not Cause CNH 12M	10	1.637788	0.050733*
CNH 12M not Cause NDF 12M	10	2.47747	0.006616***

Note: *, **, and *** denote the significance at 10%, 5% and 1% levels, respectively. We report lag=5 as an example for Nonlinear causality in this table.

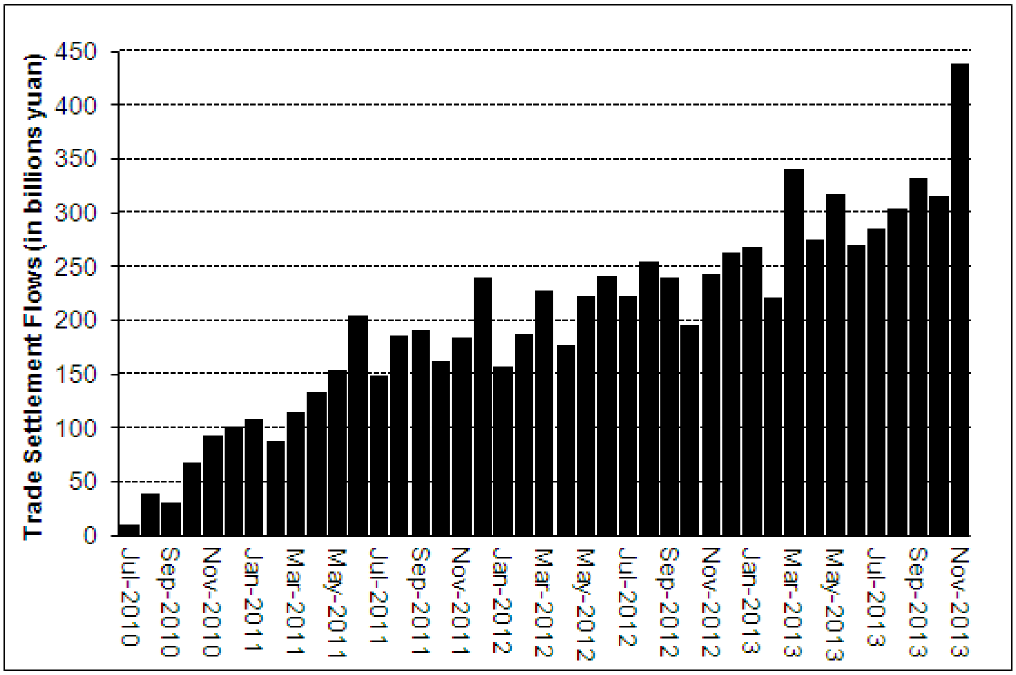
Table 14 The results of the one-step-ahead forecast during each Sub-period

	Sub-period 1				Sub-period 2				Sub-period 3			
Null Hypothesis	1	2	3	4	1	2	3	4	1	2	3	4
SPOToff not Cause SPOTon	0.0041	0.0041	0.0041	0.0042	0.0033	0.0033	0.0033	0.0033	0.0064	0.0063	0.0064	0.0065
SPOToff Cause SPOTon	0.0041	0.0042	0.0042	0.0042	0.0034	0.0033	0.0033	0.0034	0.0061	0.0059	0.0059^{*}	0.0061
SPOTon not Cause SPOToff	0.0050	0.0051	0.0051	0.0051	0.0040	0.0040	0.0040	0.0040	0.0107	0.0103	0.0104	0.0106
SPOTon Cause SPOToff	0.0053	0.0052	0.0052	0.0051	0.0038^{*}	0.0039	0.0039	0.0039	0.0106	0.0105	0.0107	0.0104^{*}
CNH 1M not Cause CNY 1M	0.0037	0.0039	0.0040	0.0042	0.0042	0.0042	0.0042	0.0042	0.0074	0.0080	0.0082	0.0083
CNH 1M Cause CNY 1M	0.0033	0.0031^{*}	0.0032	0.0033	0.0039	0.0040	0.0041	0.0040	0.0070^{*}	0.0074	0.0077	0.0079
CNY 1M not Cause CNH 1M	0.0040	0.0041	0.0041	0.0041	0.0026	0.0026	0.0026	0.0026	0.0050	0.0051	0.0052	0.0050
CNY 1M Cause CNH 1M	0.0040	0.0041	0.0042	0.0041	0.0026	0.0025^{*}	0.0026	0.0026	0.0048^{*}	0.0052	0.0051	0.0050
CNH 3M not Cause CNY 3M	0.0046	0.0045	0.0045	0.0046	0.0154	0.0155	0.0158	0.0161	0.0310	0.0295	0.0296	0.0284
CNH 3M Cause CNY 3M	0.0042	0.0037	0.0037	0.0038	0.0152	0.0150^{*}	0.0155	0.0157	0.0307	0.0292	0.0295	0.0287
CNY 3M not Cause CNH 3M	0.0048	0.0049	0.0049	0.0047	0.0027	0.0027	0.0027	0.0027	0.0074	0.0072	0.0073	0.0075
CNY 3M Cause CNH 3M	0.0049	0.0050	0.0048	0.0048	0.0029	0.0030	0.0034	0.0034	0.0074	0.0072	0.0072	0.0075
CNH 6M not Cause CNY 6M	0.0049	0.0045	0.0046	0.0047	0.0098	0.0099	0.0101	0.0098	0.0088	0.0090	0.0090	0.0092
CNH 6M Cause CNY 6M	0.0049	0.0038^{*}	0.0039	0.0040	0.0095^{*}	0.0097	0.0099	0.0098	0.0086^{*}	0.0089	0.0093	0.0095
CNY 6M not Cause CNH 6M	0.0062	0.0062	0.0062	0.0060	0.0036	0.0036	0.0036	0.0036	0.0093	0.0093	0.0092	0.0097
CNY 6M Cause CNH 6M	0.0066	0.0066	0.0064	0.0064	0.0036	0.0036	0.0037	0.0037	0.0089^{*}	0.0095	0.0098	0.0102
CNH 12M not Cause CNY 12M	0.0053	0.0049	0.0049	0.0049	0.0042	0.0043	0.0043	0.0043	0.0096	0.0100	0.0100	0.0101
CNH 12M Cause CNY 12M	0.0051	0.0040	0.0040	0.0042	0.0040^{*}	0.0041	0.0042	0.0041	0.0088^{*}	0.0093	0.0092	0.0092
CNY 12M not Cause CNH 12M	0.0077	0.0078	0.0075	0.0073	0.0040	0.0039	0.0038	0.0038	0.0115	0.0111	0.0110^{*}	0.0115
CNY 12M Cause CNH 12M	0.0083	0.0084	0.0081	0.0075	0.0041	0.0040	0.0041	0.0042	0.0113	0.0121	0.0122	0.0125
NDF 1M not Cause CNY 1M	0.0037^{*}	0.0039	0.0040	0.0042	0.0041	0.0042	0.0043	0.0043	0.0051	0.0051	0.0051	0.0050
NDF 1M Cause CNY 1M	0.0038	0.0040	0.0040	0.0043	0.0041	0.0042	0.0043	0.0044	0.0048^{*}	0.0049	0.0050	0.0050
CNY 1M not Cause NDF 1M	0.0050	0.0050	0.0050	0.0050	0.0042	0.0043	0.0043	0.0043	0.0114	0.0110	0.0110	0.0112
CNY 1M Cause NDF 1M	0.0054	0.0051	0.0051	0.0053	0.0042^{*}	0.0043	0.0045	0.0045	0.0110	0.0108^{*}	0.0108	0.0110

NDF 3M not Cause CNY 3M	0.0046	0.0115	0.0116	0.0125	0.0150	0.0149	0.0153	0.0156	0.0300	0.0297	0.0302	0.0300
NDF 3M Cause CNY 3M	0.0045*	0.0124	0.0122	0.0131	0.0149	0.0149*	0.0152	0.0155	0.0296	0.0296	0.0304	0.0300
CNY 3M not Cause NDF 3M	0.0051*	0.0114	0.0115	0.0115	0.0047*	0.0048	0.0048	0.0048	0.0123	0.0119	0.0120	0.0124
CNY 3M Cause NDF 3M	0.0059	0.0109	0.0109	0.0114	0.0049	0.0054	0.0058	0.0059	0.0123	0.0119	0.0119	0.0123
NDF 6M not Cause CNY 6M	0.0049	0.0072	0.0074	0.0080	0.0093*	0.0094	0.0098	0.0094	0.0079	0.0081	0.0082	0.0082
NDF 6M Cause CNY 6M	0.0045*	0.0085	0.0087	0.0095	0.0094	0.0096	0.0099	0.0095	0.0077*	0.0082	0.0078	0.0079
CNY 6M not Cause NDF 6M	0.0061*	0.0115	0.0115	0.0115	0.0050	0.0049	0.0050	0.0050	0.0131	0.0126*	0.0127	0.0130
CNY 6M Cause NDF 6M	0.0068	0.0105	0.0106	0.0107	0.0050	0.0050	0.0055	0.0054	0.0128	0.0135	0.0139	0.0134
NDF 12M not Cause CNY 12M	0.0053	0.0056	0.0057	0.0059	0.0039	0.0040	0.0039	0.0039	0.0087	0.0090	0.0089	0.0090
NDF 12M Cause CNY 12M	0.0049*	0.0074	0.0079	0.0081	0.0039	0.0039	0.0041	0.0041	0.0086	0.0091	0.0083*	0.0084
CNY 12M not Cause NDF 12M	0.0067*	0.0107	0.0106	0.0107	0.0060	0.0062	0.0062	0.0062	0.0145	0.0144	0.0145	0.0148
CNY 12M Cause NDF 12M	0.0070	0.0104	0.0106	0.0104	0.0060	0.0061	0.0063	0.0063	0.0143*	0.0157	0.0159	0.0160
NDF 1M not Cause CNH 1M	0.0040*	0.0201	0.0196	0.0196	0.0026*	0.0026	0.0026	0.0026	0.0051	0.0051	0.0051	0.0050
NDF 1M Cause CNH 1M	0.0041	0.0191	0.0188	0.0183	0.0026	0.0026	0.0027	0.0027	0.0048*	0.0049	0.0050	0.0050
CNH 1M not Cause NDF 1M	0.0050*	0.0122	0.0123	0.0124	0.0046	0.0047	0.0047	0.0047	0.0114	0.0110	0.0110	0.0112
CNH 1M Cause NDF 1M	0.0057	0.0122	0.0120	0.0117	0.0045*	0.0046	0.0046	0.0046	0.0110	0.0108*	0.0108	0.0110
NDF 3M not Cause CNH 3M	0.0048*	0.0219	0.0211	0.0210	0.0027	0.0027	0.0027	0.0027	0.0076	0.0074	0.0075	0.0076
NDF 3M Cause CNH 3M	0.0049	0.0211	0.0205	0.0199	0.0027	0.0027	0.0027	0.0027	0.0076	0.0074	0.0078	0.0078
CNH 3M not Cause NDF 3M	0.0051*	0.0114	0.0115	0.0115	0.0047	0.0048	0.0048	0.0048	0.0126	0.0121	0.0122	0.0126
CNH 3M Cause NDF 3M	0.0054	0.0099	0.0098	0.0093	0.0046	0.0047	0.0047	0.0046*	0.0123	0.0120*	0.0121	0.0124
NDF 6M not Cause CNH 6M	0.0062	0.0196	0.0190	0.0185	0.0035	0.0035	0.0035	0.0035	0.0091	0.0092	0.0091	0.0095
NDF 6M Cause CNH 6M	0.0061*	0.0194	0.0192	0.0184	0.0035	0.0034	0.0035	0.0034	0.0092	0.0092	0.0098	0.0100
CNH 6M not Cause NDF 6M	0.0062	0.0115	0.0115	0.0115	0.0051	0.0051	0.0051	0.0051	0.0127	0.0124	0.0125	0.0128
CNH 6M Cause NDF 6M	0.0058*	0.0109	0.0109	0.0104	0.0051	0.0051	0.0051	0.0050	0.0129	0.0126	0.0128	0.0134
NDF 12M not Cause CNH 12M	0.0077*	0.0211	0.0205	0.0197	0.0040	0.0038	0.0038	0.0038	0.0115	0.0112	0.0111*	0.0116
NDF 12M Cause CNH 12M	0.0082	0.0203	0.0202	0.0195	0.0041	0.0040	0.0039	0.0040	0.0116	0.0114	0.0116	0.0122
CNH 12M not Cause NDF 12M	0.0067	0.0107	0.0106	0.0107	0.0060	0.0062	0.0062	0.0062	0.0139	0.0139*	0.0140	0.0142
CNH 12M Cause NDF 12M	0.0072	0.0111	0.0111	0.0109	0.0059	0.0060	0.0060	0.0060	0.0140	0.0141	0.0142	0.0149

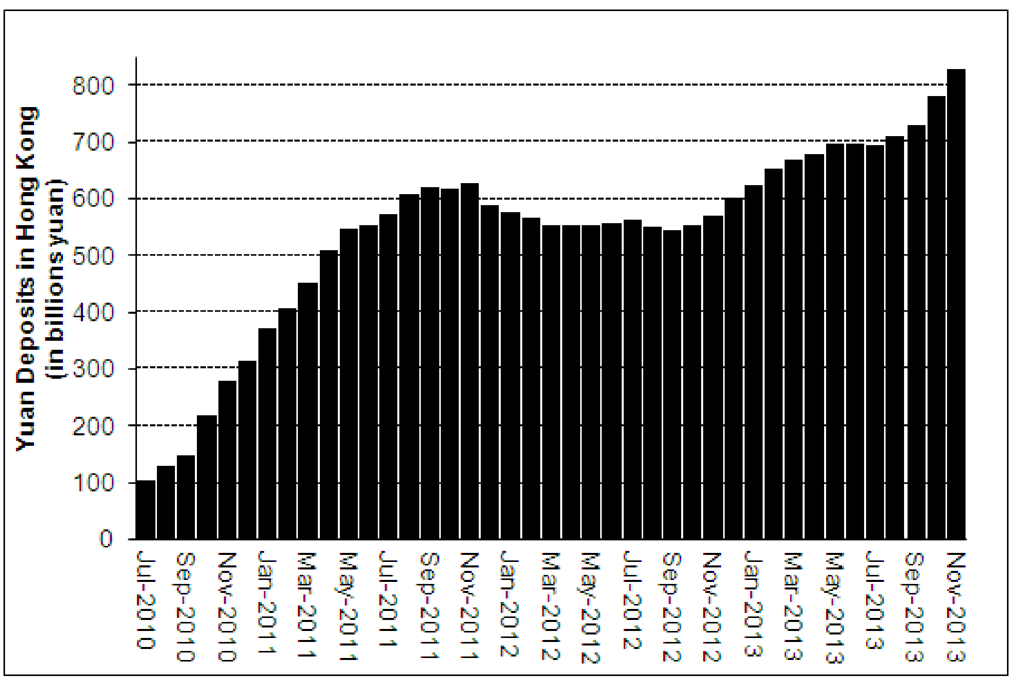
Note: * denotes the smallest mean absolute error between the pair of opposite hypotheses. We only report the results of the first 4 lags for each period and skip reporting the results from lag 6 to lag 10 for simplicity.

Figure A1. Remittances for Yuan cross-border trade settlement with Hong Kong.banks



Source: Bloomberg

Figure A2. Yuan deposits in Hong Kong



Source: Bloomberg