Exchange Rate Regimes and Market Integration: Evidence from the Dynamic Relations between the Renminbi Onshore and Offshore Markets*

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Abstract

This paper examines the dynamic conditional correlations and spillovers between daily return changes in the Renminbi (RMB) onshore and offshore markets, and link them to the exchange rate regime. We find that flexible exchange rates are prone to market integration and promote information flows, mainly from the offshore market to the onshore market, and that there are a correlation jump and a spillover reversal when the RMB exchange rate regime switches from a pegged system to a managed floating system in July 2005. These findings have important implications for China's monetary and foreign exchange policies and shed light on the internationalization of the RMB.

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Keywords: RMB internationalization; Non-deliverable forward; Correlation jump; Spillover reversal.

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1 Introduction

Many countries, especially developing countries, have experienced switches in exchange rate regimes and ever changing degrees of the integration of their financial market with the world. Along these processes arise important questions such as: Does the switching of the exchange rate regime from a pegged system to a more flexible one promotes integration between domestic and international financial markets? Does the flexibility of the exchange rate impact information flows between onshore and offshore exchange markets? Can the monetary authorities retain the pricing power on the offshore markets if they ease regulations and interventions on the foreign exchange markets? These questions have not been fully examined, in particular in the context of a large developing financial system such as that of China.

China's foreign exchange policy has been highly controversial over the last two decades and will continue to receive considerable attention in the foreseeable future as China is playing a more and more important role in the global financial market. The exchange rate reform launched in July 2005 has been commonly viewed as a milestone, indicating the end of China's *de facto* fixed exchange rate regime and the move to a more flexible exchange rate arrangement (Frankel and Wei, 2007). Since then, China's foreign exchange arrangements have kept changing with all kinds of detailed regulation measures and trading restrictions. But the big picture is that the managed float reverted to a peg against the U.S. dollar (USD) from September 2009 to June 2010 in an attempt to avoid a slump in China's export growth that might otherwise be caused by the Global Financial Crisis (GFC), and that the RMB exchange rate regained flexibility when this peg was lifted. In our view, these experiences provide a precious opportunity to address the questions posed above by exploiting the time variations (the occurence and recurrence of peg/float) in the RMB exchange rate regime.

The People's Bank of China (PBC), China's central bank, can enjoy direct control over the level and floating range of the spot exchange rate in the onshore market if it wants. The question is whether it can influence the market expectation in the international market. Another response of the Chinese government to the GFC is the active promotion of the international use of the Renminbi (RMB). Historical experience suggests that an offshore market is essential for a global currency (Cheung, 2014), and the non-deliverable forward (NDF) contract is one of the key instruments in offshore markets for investors to hedge and take positions in countries subject to currency regulations and/or capital account control. Market segmentation arises due to various kinds of impediments to international investment, and the extent of segmentation changes from time to time. Understanding the dynamic relations between the domestic currency market and the offshore NDF market, which reflects overseas investors' expectation of the future exchange rate, is vital not only for the academia but also the practitioners and policy-makers.

To investigate the impact of the exchange rate regime on the interrelation between the RMB onshore and offshore markets, we employ daily data with a long period from April 26, 1999 to the end of 2012, encompassing multiple episodes of fixed exchange rates and those of managed floating. We consider four distinct periods for the RMB exchange rate regime: (i) the pre-reform period (April 26, 1999-July 20, 2005) of exchange rate peg, (ii) the early post-reform period (July 21, 2005-August 30, 2009) of managed floating, (iii) the re-peg period (September 1, 2009-June 18, 2010), and (iv) the late post-reform period (June 19, 2010-December 30, 2012) of managed floating. Our first step is to explore the evolving nature of market integration. We use a GARCH model with dynamic conditional correlations (DCCs), developed by Engle (2002), to estimate the time-varying correlations between the daily return changes in the RMB onshore and offshore markets. The second step is to investigate information flows across markets, following the Hamao et al. (1990)'s spillover effect model. We examine both the mean and volatility spillovers, and link them to the RMB exchange rate regime.

Our main findings are summarized as follows. (i) There is a striking *correlation jump* on the day immediately after the exchange rate reform on July 21, 2005, which switches the RMB exchange rate regime from pegged to managed floating. (ii) There is a correlation collapse when the RMB is pegged again to the USD from September 2009 to June 2010, and a correlation rebound when that second peg is lifted subsequently. The dynamic patterns of the conditional correlations suggest that a flexible exchange rate regime is associated with larger intermarket correlations, while a pegged regime is associated with smaller, close to zero correlations. Therefore flexible exhange rates are prone to market integration. (iii) Whenever the RMB is in a (managed) floating regime, the offshore market becomes the absolute pricing center for the RMB: the spillover mainly runs from the offshore market to the onshore market, meaning that the PBC loses the pricing power on the offshore market. (iv) There is a *spillover reversal* when the exchange rate reform takes place in 2005. The direction of spillover turns from onshore-to-offshore in the pre-reform period to offshore-to-onshore in the early post-reform period. (v) The spillovers are much stronger under floating regimes. The spillover effects are either insignificant or small when the RMB is pegged. These results provide an information basis for the correlation results found from the DCC-GARCH model.

This paper contributes to the literature by providing evidence on the link between exchange rate regimes and market integration from the largest emerging economy with an evolving financial system. Previous studies linking exchange rate regimes to currency markets mainly focus on the relation between exchange rate regimes and currency risks (Ghosh et al. 2003, Bubula and Ötker-Robe 2003, Rogoff et al. 2004, and Husain et al. 2005, among others). To date there has been little research analyzing the impact of changes in the exchange rate regime on onshore-offshore market integration and cross-market information flows. Park (2001) explicitly links cross-market information flows to the reform in the exchange rate system, based on the Korean experience. He finds that the movement of the Korean exchange rate system from managed floating to free floating in December 1997 reverses the directions of spillovers between the Korean Won spot and NDF markets. After the reform, the spillovers exist from the NDF market to the spot market, but not the other way round. Other than looking at the experience of a different country, an importance difference of our paper from Park's is that he uses data on changes in the exchange rate on the onshore and offshore markets, while we base our study on exchange rate-adjusted return changes. Although exchange rate movements per se contain much useful information and have been fruitfully explored by many other studies, they are not our preferred choice. We provide the theoretical underpinning for our methodology for the construction of variables in Section 3.1, which is motivated by the covered interest parity (or disparity).

Maziad and Kang (2012) explore the interrelation between RMB onshore and offshore markets during the process of RMB internationalization. Their sample, covering the period from August 23, 2010 to September 16, 2011, does not allow them to investigate the impact of changes in the RMB exchange rate regime on the onshore-offshore linkage. To the best of our knowledge, our paper is the first in the literature to systematically analyze the impact of the RMB exchange rate regime on the dynamic conditional correlations as well as information flows between the RMB onshore and offshore markets, a topic that has not received the attention it deserves.

The rest of the paper is organized as follows. Section 2 provides some background information and describes the data. Section 3 briefly discusses the empirical methodology. The benchmark results are presented in Section 4, followed by robustness checks in Section 5. The last section concludes.

2 Background and Data

2.1 China's Exchange Rate Regimes and the RMB NDF Market

The RMB was pegged against the USD since December 1997 at 8.27 yuan/dollar till China launched the exchange rate reform in July 21st, 2005. On that day, the PBC revalued the RMB by 2.1% against the USD. It also indicated the move of the RMB from a pegged to a more flexible exchange rate arrangement. The PBC, nevertheless, maintains significant power to intervene on the spot exchange market. It decides directly on the range for the daily changes in the spot exchange rate. Once the daily change exceeds the range, the spot exchange market will be closed automatically. Since 2005, the range has been widened several times. The floating band of the RMB's trading prices against the USD in the interbank foreign exchange market was changed from 0.5% to 1% in April 2012, and further to 2% in April 2014.

Even when the RMB was pegged to the USD before 2005, foreign investors were concerned about the potential currency risk of the RMB. For example, in the aftermath of the Asian Financial Crisis, investors worried about the depreciation of the RMB. On the other hand, there was considerable pressure from the U.S. for the RMB to be revalued since 2003 (Higgins and Humpage, 2005). The possibility of exchange rate reform was another source of currency risk.

The NDF contract is one of the key tools in offshore markets for investors to hedge and take positions on countries subject to currency regulations and/or capital account control. Although the domestic forward market started in 1997, only one bank, the Bank of China, could provide this business before 2005. The development of domestic forward market was very limited and slow before the exchange rate reform, and only enterprises that had direct investment in China could engage in the onshore forward market. As a result, the RMB NDF market in Hong Kong played a leading role in hedging currency risk or taking speculative currency positions for both domestic and overseas investors, especially after the Asian Financial Crisis. The maturities of RMB NDFs are mainly less than one year, and the spread of the one-month maturity NDF is usually the lowest, indicating that the one-month NDF contract has higher liquidity and trading volume.

The NDF is a currency forward contract in which cash settlement occurs instead of physical delivery. Asian NDF markets established in the mid 1990s were in part a response of the banks and brokers to government restrictions on onshore forward contracts. While exporters and importers have found forward contracts a useful device for hedging currency risk, governments have often viewed these instruments as a vehicle for speculative capital account activity. During the Asian Financial Crisis, several governments took actions to limit the scope and activities of the NDF markets. This reflected a belief that the offshore Asian NDF markets did provide a vehicle for speculation against local currencies.

2.2 Data

Our study concentrates on the dynamic relations between the exchange rate-adjusted return changes in the RMB onshore and offshore markets. Let S_t be the yuan/dollar spot exchange rate, F_t be the forward rate, and i_t^{rmb} and i_t^{usd} be the China and U.S. interest rates, respectively. The exchange rate-adjusted return in the onshore market is defined as $S_t \times \left(1 + i_t^{rmb}\right)$, whereas the exchange rate-adjusted return in the offshore market is defined as $F_t \times \left(1 + i_t^{usd}\right)$. We motivate the use of these return series in the Section 3.1.

In order to construct the exchange-rate adjusted market returns, we employ data on the daily closing rates for the official spot exchange rate and the NDF rate, as well as the China interbank rate (Chibor) and the London interbank rate (Libor) for the USD. The spot exchange rate and Chibor are obtained from the CEIC database, while data for the NDF rate and Libor are from Bloomberg. The data cover April 26, 1999 to December 30, 2012.[1] Figure 1 plots the daily spot rate and the NDF rates for 1, 3, 6 and 12-month contracts. As the one-month NDF contract has the lowest spread[2], indicating that this

[1]The earliest available data for the NDF rate are in 1999.

[2]Spreads are measured here as the gaps between forward bid and ask prices, divided by the corresponding spot rates.

maturity has the highest liquidity, we choose the one-month NDF rate to be the variable F_t.

[Insert Figure 1 about here.]

There are four distinct periods for the spot exchange rate. (i) The pre-reform period (April 26, 1999-July 20, 2005). The spot exchange rate was pegged at 8.27 before the exchange rate reform in 2005. (ii) The early post-reform period (July 21, 2005-August 30, 2009). The spot rate began to fall after the reform. It reached 6.82 in September 2009, implying a nearly 17.5 percent appreciation of the RMB against the USD in four years. (iii) The re-peg period (September 1, 2009-June 18, 2010). In order to avoid a slump in the Chinese economy which could potentially result from the impact of the GFC, the Chinese government implemented a stimulus package, including nation-wide infrastructure investment and tax reduction, etc. Meanwhile, the spot exchange rate between the RMB and the USD was pegged again at 6.82 in order to keep the exchange rate stable and to prevent the RMB from appreciating further, which was intended for the avoidance of a potential sharp reduction in export growth. (iv) The late post-reform period (June 19, 2010-December 30, 2012). After being pegged for 9 months, the spot exchange rate was allowed to be flexible again. It reached 6.23 at the end of 2012, resulting in an appreciation of the RMB by 25 percent since the exchange rate reform took place in July 2005.

It is worth noticing that the relative levels of the spot rate and the NDF rate have changed over time. As shown in Figure 1, the NDF rate began to be lower than the spot rate since November 2002.[3] There was huge pressure (mainly from the U.S.) for China to revalue the RMB, and the gap between the spot rate and the NDF rate reflected the market expectation of appreciation on the RMB. This trend lasted until the GFC erupted in 2008. Since then, the NDF rate was sometimes higher than the spot rate and lower at other times, indicating the end of the appreciation expectation on the RMB.

Figure 2 shows the daily Chibor and U.S. Libor with one month maturity. Both change a lot over time. The Chibor is apparently more volatile than the U.S. Libor. The highest level of Chibor obtained in November 2007, when the PBC raised the reserve requirement for the tenth time in the same year. This was meant to temper the excess liquidity in China's banking system. One popular explanation for the excess liquidity is the large trade surplus coupled with a strong appreciation expectation on the RMB since 2003. After the GFC, the U.S. Libor nearly hit the zero lower bound, while the Chibor hiked to its second peak in early 2012 when the PBC's stance was tightened to curtail domestic inflation.

[Insert Figure 2 about here.]

3 Methodology

In this section, we first motivate the construction of the exchange rate-adjusted returns. We then briefly outline the DCC-GARCH model which is used to estimate the time-varying correlations for the return series. Finally, we specify an extended GARCH model to explore information flows between the RMB onshore and offshore markets.

[3] This is consistent with the finding by Fung et al. (2004) that the forward premium (RMB/USD) becomes discount for various maturities of RMB NDF after November 2002.

3.1 Theoretical Underpinning

Our study of the interrelation between the onshore and offshore markets for the RMB is motivated by the covered interest parity equation, which would hold in theory if markets are perfectly integrated. The equation links interest rates with exchange rates in the following way:

$$F_t = S_t \times \left(1 + i_t^{rmb}\right) / \left(1 + i_t^{usd}\right), \tag{1}$$

where S_t is the yuan-dollar spot exchange rate (yuan per dollar), F_t is the forward exchange rate, and i_t^{rmb} and i_t^{usd} are the China and U.S. interest rates, respectively.

One way to examine whether the covered interest parity holds is to compute the implied forward exchange rate—the right-hand side of equation (1) and to compare it with the actual forward rate. Figure 3 plot the implied one-month forward rate (IPF1) and the actual NDF rate (NDF1), also for the one-month maturity. It can be seen that before the exchange rate reform in 2005, the implied forward rate fluctuated by a great deal, while the actual NDF rate was fairly stable. The volatility of the implied forward rate came from fluctuations in the interest rates since the spot exchange rate was pegged in the pre-reform period. After the exchange rate reform, the two series appear to comove to some extent.

[Insert Figure 3 about here]

There is, however, a disadvantage of using the implied forward rate to study the dynamic relations between the onshore and offshore markets. Specifically, IPF1 contains mixed information as it includes both domestic and foreign variables. The same issue applies to an alternative method of looking at the "covered interest differential," defined as the log of the right hand side of equation (1) minus the log of the left-hand side.[4] Although the size of the covered interest differential is a useful measure for international capital mobility (Frankel, 1992), it is not the best choice for our purpose since we are primarily concerned with dynamic interactions between markets. To this end, we need to separate information pertinent to the onshore market from information pertinent to the offshore market.

The above consideration leads us to rewrite equation (1) as

$$F_t \times \left(1 + i_t^{usd}\right) = S_t \times \left(1 + i_t^{rmb}\right), \tag{2}$$

and to examine the dynamic relations between the two sides of equation (2). For markets that are perfectly integrated, equation (2) implies that the exchange rate-adjusted return in the offshore market, $F_t \times \left(1 + i_t^{usd}\right)$, should be perfectly correlated with the exchange rate-adjusted return in the onshore spot market, $S_t \times \left(1 + i_t^{rmb}\right)$. But for markets that are highly segmented, the returns would be virtually uncorrelated with each other.

Since the return series are I(1) as confirmed by unit-root tests, we look at their daily changes, defined as the negative of the percentage change of the current day exchange rate-adjusted return from the previous day.[5] Figure 4 plots the two daily return change series. The onshore series is labeled $\Delta RSPOT$ and the offshore series $\Delta RNDF$. Our purpose is to investigate the dynamic correlations between the onshore and offshore return

[4] In practice, the log of the gross interest rate is approximated by the net interest rate, so the covered interest differential is calculated as the gap between the domestic nominal interest rate and foreign nominal interest rate minus the forward discount on the domestic currency.

[5] In this definition, a positive change would mean an appreciation of the RMB if the interest rates were constant.

change series, as well as the spillovers between them.

[Insert Figure 4 about here]

Table 1 presents the descriptive statistics for $\Delta RSPOT$ and $\Delta RNDF$ for the four periods considered. The volatilities of the onshore market are larger than those of the offshore market, especially before the exchange rate reform of 2005. This indicates that although the RMB spot exchange rate was stablizied with the aid of various regulations and capital control measures, the interbank interest rate was quite volatile, which can be seen as an implicit cost of exchange rate stablization. The skewness statistics indicate that the two series are asymmetrically distributed.

[Insert Table 1 about here]

3.2 DCC-GARCH

GARCH models have become standard methods to characterize the conditional heteroscedasticity for many financial time series.[6] Let $r_{i,t}$ denote the daily return change in market i at time t, $i = 1, 2$. It is assumed to be generated by the following process:

$$r_{i,t} = \mu_{i,t} + \varepsilon_{i,t}, \tag{3}$$

$$\varepsilon_{i,t} = h_{i,t}^{1/2} \eta_{i,t}, \tag{4}$$

$$h_{i,t} = \omega_i + \delta_i \varepsilon_{i,t-1}^2 + \theta_i h_{i,t-1}. \tag{5}$$

Here $\mu_{i,t}$ is the conditional mean of $r_{i,t}$ containing a constant plus an AR(1) term. The demeaned return series $\varepsilon_{it} = r_{i,t} - \mu_{i,t}$ has i.i.d. standardized residuals $\eta_{i,t}$ after the

[6] See Engle (1982) and Bollerslev (1986) for the original development of the approach. Liu and Pauwels (2012) investigate whether external political pressure for faster RMB appreciation affects the daily returns and the conditional volatility of the RMB NDF rate.

conditional volatility $h_{i,t}^{1/2}$ is filtered. In the robustness check we will also consider an asymmetric GARCH specification where positive and negative shocks have different impacts on volatilities (see Section 5). Ling and Li (1997) show that a GARCH model is strictly stationary and ergodic if the second moment is finite, that is, if $E\left(\varepsilon_t^2\right) < \infty$. According to Ling and Li (1997) and Ling and McAleer (2002a, b), the necessary and sufficient condition for a finite second moment for GARCH(1,1) is $\delta_i + \theta_i < 1$.

The time-varying conditional covariance matrix for the demeaned returns may be written as

$$H_t = D_t R_t D_t, \tag{6}$$

where $D_t = diag\left\{\sqrt{h_{1,t}}, \sqrt{h_{2,t}}\right\}$ is a diagonal matrix, and R_t represents the conditional correlation matrix for the standardized residuals $\eta_t = \left[\eta_{1,t}\ \eta_{2,t}\right]'$. The matrix R_t is constructed in the following way. Let $Q_t = \{q_{ij,t}\}$ be the conditional covariance matrix for η_t. The elements in Q_t can be used to compute the conditional correlation, $\rho_{ij,t}$, between $\eta_{i,t}$ and $\eta_{j,t}$: $\rho_{ij,t} = q_{ij,t}/\sqrt{q_{ii,t}q_{jj,t}}$. In matrix notations, $R_t = diag\left\{Q_t\right\}^{-1} Q_t diag\left\{Q_t\right\}^{-1}$.

We adopt the diagonal version of the DCC model proposed by Engle (2002) to model conditional covariance. We consider the following mean-reverting model:

$$q_{ij,t} = \bar{\rho}_{ij} + \alpha\left(\eta_{i,t-1}\eta_{j,t-1} - \bar{\rho}_{ij}\right) + \beta\left(q_{ij,t-1} - \bar{\rho}_{ij}\right), \tag{7}$$

where α and β are scalar parameters, and $\bar{\rho}_{ij}$ is the unconditional expectation of the cross product of η_{it} and η_{jt}. In matrix notations,

$$Q_t = S\left(1 - \alpha - \beta\right) + \alpha\eta_{t-1}\eta_{t-1}' + \beta Q_{t-1}, \tag{8}$$

where S is the unconditional correlation matrix of η_t, which in the estimation procedure is replaced by the sample correlation matrix of η_t.

Estimation is carried out by maximizing the log likelihood function of the DCC model. One major advantage of DCC-GARCH models is that the log likelihood function can be written as the sum of a volatility part and a correlation part (see Engle, 2002):

$$L(\Theta, \Phi) = L_V(\Theta) + L_C(\Theta, \Phi), \tag{9}$$

where Θ denotes the parameters in $\{D_t\}$ and Φ the additional parameters in $\{R_t\}$. The separability in (9) makes the estimation a simple two-step procedure. First, we estimate the univariate GARCH models and obtain $\hat{\Theta}$. Then, Φ is estimated given $\hat{\Theta}$. This feature gives the DCC model considerable computational advantages over alternative models for time-varying correlations. As Engle (2002) shows, the DCC estimator still has the QMLE interpretation even when the error terms are not normal. This is particularly useful in our context since the market returns are typically non-normal.

3.3 Spillovers

Although the DCC-GARCH model allows us to investigate the time-varing correlations between the daily return changes in the onshore and offshore markets, it does not tell anything about why and how the correlation emerges, that is, it is silent on the directions of causation for return movements between markets. In order to explore the directions of information flow, we follow Hamao et al. (1990) to incorporate spillover effects into the GARCH model.[7] Specifically, we examine the spillover effects between the onshore and

[7] Hamao et al. (1990) focuse on spillovers between stock markets.

offshore markets using the following model:

$$r_{i,t} = \mu_{i,t} + \tau_i r_{j,t-1} + \varepsilon_{i,t}, \tag{10}$$

$$h_{i,t} = \omega_i + \delta_i \varepsilon^2_{i,t-1} + \theta_i h_{i,t-1} + \chi_i \varepsilon^2_{j,t-1}, \tag{11}$$

where $r_{j,t-1}$ represents the previous return change in the counterpart market, and $\varepsilon_{j,t-1}$ is the last-period residual derived from the GARCH (1,1) model applied to $r_{j,t}$. For the test of spillover effects, the parameters of interest are τ_i and χ_i, $i = 1, 2$. If τ_i is significant, we say that there is a spillover effect from market j to market i in conditional mean (mean spillover). On the other hand, if χ_i is significant, there is spillover from market j to market i in conditional volatility (volatility spillover).[8] It is important to point out that we do not rule out the causation of any direction *a priori*.

4 Results

In this section, we present the estimation results of the DCC-GARCH models for the daily return changes, as well as the estimation and test results for the spillover effects between the RMB onshore and offshore markets. The DCC-GARCH model is applied to the whole sample (April 26, 1999 to December 31, 2012). That is, we do not assume any correlation jumps *a priori*. The spillover effect model is applied to each of the four periods specified in Section 2.2. This seems appropriate, given the different correlation patterns we find for different periods.

[8] Clark (1973), Tauchen and Pitts (1983), and Ross (1989) emphasize the importance of asset return volatilities to the rate of information flow to markets.

4.1 Dynamic Conditional Correlations

Table 2 reports the estimation results for the benchmark GARCH models for $\Delta RSPOT$ and $\Delta RNDF$ (the two columns under "Symmetric"). The second-moment conditions are satisfied for the QLME. Whichever the series is, the GARCH effect parameter (θ_i) is statistically significant at the 1% level, indicating volatility clustering of both series. The onshore and offshore markets exhibit different patterns in some respects. In particular, the GARCH effect in the onshore market is larger than that in the offshore market. This means that, relatively speaking, the volatility in the onshore market is explained more by its past behavior.

[Insert Table 2 about here.]

The DCC estimation results are displayed in Table 3, from which we see that the estimated DCC parameters are statistically significant. This makes it clear that the assumption of constant conditional correlation is not supported by the data. The time-varying nature of the conditional correlation is highlighted in Figure 5a. Two observations stand out. First, there is a striking *correlation jump* on the day immediately after the exchange rate reform on July 21, 2005. Before the reform the RMB was pegged to the USD. The correlation between the onshore and offshore daily return changes was close to zero in this pre-reform period. The exchange rate reform moved the RMB to a more flexible regime. The regime change immediately sent the value of the onshore-offshore correlation to about 0.25 on July 22, 2005. The correlation remained significantly higher during the early post-reform period than the post-reform period. Second, when the RMB exchange rate was pegged again to the USD from September 2009 to June 2010, the onshore-offshore correlation dropped substantially (to an average value of less than 0.1 for the re-peg period), a *correlation collapse.* And when the RMB exchange rate was allowed to fluctuate again after the peg was lifted, there was a *correlation rebound.* In sum, the dynamic patterns displayed in the Figure suggest that a flexible exchange rate regime is associated with larger correlations between the onshore and offshore daily return changes, while a pegged regime is associated with smaller, close to zero correlations. Although the correlations are still not very large in the early and late post-reform periods, the comparison to the pre-reform and the re-peg periods indicates that the flexibility of the RMB exchange rate produces stronger integration between the onshore and offshore markets.

[Insert Table 3 about here.]

[Insert Figures 5a & 5b about here.]

Table 4 presents the summary statistics for the estimated conditional correlations. The mean of the correlation increases from 0.05 before the reform to about 0.19 after the reform. Both the t-test for mean equality and the Kruskal-Wallis test for median equality show that the average correlation between the onshore and offshore markets increases significantly after the exchange rate reform on July 21, 2005. The summary statistics also show the decline in the correlation when the RMB exchange rate was re-pegged and the correlation rebound when the exchange rate floated again. The average correlations for the early post-reform period, the re-peg period, and the late post-reform period are 0.186, 0.094, and 0.160, respectively.

[Insert Tables 4a & 4b about here.]

4.2 Spillovers

The advantage of studying the spillovers between markets is that it allows us to explore the *directions* of information flows. It also provides an information perspective for explaining the changing patterns of the dynamic conditional correlations between the RMB onshore and offshore markets.

In the spillover-effect model of (10)-(11), the variable $r_{j,t-1}$ represents the return change in the counterpart market on the previous trading day, and the variable $\varepsilon^2_{j,t-1}$ represents the previous day's squared error from the GARCH(1,1) model applied to the variable r_j. The coefficient (τ_i) of $r_{j,t-1}$ indicates the spillover effect of market j on the conditional mean in market i. The coefficient (χ_i) of $\varepsilon^2_{j,t-1}$ indicates the volatility spillover effect of market j on market i. The estimation and test results are reported in Table 5a.

[Insert Table 5a about here.]

During the pre-reform period, there were mean and volatility spillovers from the onshore market to the offshore market, but not the other way round. The offshore market did combine the onshore information into the pricing of NDF. Since the RMB exchange rate was pegged, the onshore information pertains to changes in China's domestic interest rate. The lack of information flow from the offshore market to the onshore market indicates that the PBC enjoyed independency in setting interest and exchange rate policy before the reform. It should be noted that the (onshore-to-offshore) spillover effects during this period are small, compared to the spillover effects when the RMB is allowed to float after the reform. Also note that the mean spillover from the onshore market to the offshore market, though significant, was negative during the pre-reform period.

As the RMB exchange rate regime switched from the pegged system to a managed floating system, a *spillover reversal* occured. After the nearly decade-long peg of the RMB against the USD was lifted, there was a large appreciation expectation on the RMB, and this expectation drove the movements in the offshore NDF market. First, there is a *direction reversal* for the spillover effect. During the early post-reform period, a significant spillover effect (in mean) ran from the offshore market to the onshore market and not the other way round. Second, there is a *sign reversal*. The onshore-to-offshore mean spillover was negative during the pre-reform period, while the offshore-to-onshore mean spillover was positive during the early post-reform period, which is conducive to positive correlations between markets. Finally, the spillovers not only changed direction and sign, but also rose in magnitude. In fact, the onshore-to-offshore spillovers in the pre-reform period are so small that they hardly generate any correlation between the two markets that is significantly above zero, as our DCC results indicated. To the contrary, the offshore-to-onshore spillovers in the early post-reform period are strong enough to generate nontrivial inter-market correlations.

When the RMB exchange rate was re-pegged from September 2009 to June 2010, the spillovers that emerged in the early post-reform period disappeared. There were no spillover in mean or volatility betweeh the onshore and offshore markets. As the spot exchange rate was strictly pegged with the PBC's intervention on the onshore exchange market, the information of the offshore market did not impact the onshore market just as in the pre-reform period. The difference from the pre-reform period is that there was not even tiny significant spillover effect from the onshore market to the offshore market. The reason might be that market participants believed this round of pegging to the USD would be temporary and the RMB would float again in the not-too-distant future.

When the RMB was allowed to float again after the re-peg was lifted, there were mean spillovers between the two markets in *both* directions. However, the impact of the offshore market on the onshore market is much stronger than the impact in the opposite direction: the former is about 8.5 times the latter.

What we get from these findings is the following. Whenever the RMB is in a (managed) floating regime (the early and late post-reform periods), the offshore market becomes the absolute pricing center for the RMB. The onshore-to-offshore spillovers are dominated by the offshore-to-onshore spillovers. It is either the case that the onshore market does not have a significant impact on the offshore market (early post-reform), or that the onshore-to-offshore spillovers are far smaller than the offshore-to-onshore spillovers. In sharp contrast, whenever the RMB exchange rate is in a pegged regime, spillovers between markets might not exist (the re-peg period), and if they do (the pre-reform period), do not run from the offshore market to the onshore market. The different spillover results serve as an information background for the correlation results we found using the DCC-GARCH model.

5 Robustness

In this section we conduct several robustness checks for our results. Specifically, we consider an asymmetric GARCH specification, an integrated version of the DCC model, and the spillover effects under the asymmetric GARCH.

5.1 Asymmetric GARCH

Glosten, Jagannathan, and Runkle (1993) propose the asymmetric GARCH, or GJR, in order to accommodate the asymmetric impacts of positive and negative shocks. In that specification, the conditional variance is given by

$$h_{i,t} = \omega_i + \delta_i \varepsilon_{i,t-1}^2 + \gamma_i I_{i,t-1} \varepsilon_{i,t-1}^2 + \theta_i h_{i,t-1}, \tag{12}$$

where

$$I_{i,t} = \begin{cases} 0, & \varepsilon_{it} \geq 0 \\ 1, & \varepsilon_{it} < 0 \end{cases}$$

is an indicator function that distinguishes between positive and negative shocks. Ling and McAleer (2002a, b) show that for the GJR(1,1) model, the necessary and sufficient condition for $E\left(\varepsilon_t^2\right) < \infty$ is $\delta_i + \gamma_i/2 + \theta_i < 1$. McAleer et al. (2007) establish the log-moment condition for GJR(1,1), namely $E\left[\log\left(\left(\delta_i + \gamma_i I_i\left(\eta_{i,t}\right)\right)\eta_{i,t}^2 + \theta_i\right)\right] < 0$, and show that it is sufficient for the consistency and asymptotic normality of the QMLE for GJR(1,1).

The estimation results for the asymmetric GARCH, specifically GJR(1,1), are shown in the right two columns of Table 2. The asymmetric effects (the γ_i's) are significant for both $\Delta RSPOT$ and $\Delta RNDF$, implying that both the onshore and offshore markets become more volatile when the realized RMB appreciation is less than expected. Furthermore, the asymmetric effect in the offshore market is stronger than that in the onshore market, which means that when the realized appreciation of the RMB is less than expected, the volatility in the offshore market increases more than the volatility in the onshore market. In spite of the asymmetric effects, the estimation of the GARCH effects (the θ_i's) are robust across the symmetric and asymmetric specifications.

5.2 Integrated DCC

In addition to the "mean-reverting" DCC in (8), we consider the following "integrated-DCC" specification:

$$q_{ij,t} = (1 - \lambda)\, \eta_{i,t-1}\eta_{j,t-1} + \lambda q_{ij,t-1}, \tag{13}$$

where λ is a scalar parameter. In matrix notations,

$$Q_t = (1 - \lambda)\, \eta_{t-1}\eta'_{t-1} + \lambda Q_{t-1}, \tag{14}$$

Note that the mean-reverting DCC model in (8) becomes the integrated model in (14) if the sum of α and β equals one.

Table 3 show the estimation results for (8) and (14). The two versions of DCC models have similar log likelihood. Moreover, the estimated DCC parameters are robust across the symmetric GARCH and the asymmetric GARCH for both the mean-reverting DCC and the integrated DCC.

The dynamic patterns for the conditional correlations produced by the mean-reverting model and the integrated model are quite similar. And it is important to note that the correlation jump, collapse, and rebound that accompany the RMB exchange rate regime switches are rediscovered under the integrated DCC. In fact, according to Table 4a, the integrated DCC produces a larger correaltion jump (from 0.015 pre-reform to 0.219 early post-reform) than the mean-reverting DCC (from 0.050 pre-reform to 0.186 early post-reform). This is also evident from Figures 5a and 5b. Examing both Table 4a and Table 4b, we see that our dynamic conditional correaltion results are robust across the symmetric GARCH and the asymmetric GARCH.

5.3 Spillovers with Asymmetric GARCH

As a final robustness check, we extend the spillover-effect model to incorporate the asymmetry for shock impacts. Specifically, (11) is modified to

$$h_{i,t} = \omega_i + \delta_i \varepsilon^2_{i,t-1} + \gamma_i I_{i,t-1} \varepsilon^2_{i,t-1} + \theta_i h_{i,t-1} + \chi_i \varepsilon^2_{j,t-1}, \tag{15}$$

where $I_{i,t-1}$ is as defined before. Comparing Table 5b to Table 5a, we find that the estimates of the spillover effects are robust against the asymmetry introduced for all the four periods we consider. In the pre-reform period, the spillover effects held only from the onshore market to the offshore market. The volatility spillover was small, and the mean spillover took the negative sign. There was again a spillover reversal after the exchange rate reform took place in 2005 under the asymmetric GARCH. The major difference from the results under the symmetric GARCH is that the volatility spillover becomes significant during the early post-reform period under the asymmetric GARCH, though it took a small value. When the RMB exchange rate was re-pegged, there is no spillover either from onshore to offshore or the other way round. During the late post-reform period, there were significant mean spillovers in both directions, with the offshore-to-onshore spillover far stronger than the onshore-to-offshore spillover.

6 Conclusions

In this paper we have examined the impact of RMB exchange rate regime on the integration and information flows between the RMB onshore and offshore markets. It is found that flexible exchange rates are prone to market integration and promote information flows, mainly from the offshore market to the onshore market. There are a correlation jump and a spillover reversal when the RMB exchange rate regime switches from a pegged system to a managed floating system in July 2005.

Our empirical findings have several important implications. First, consistent with the predictions of standard theory, the more integrated are the onshore and offshore markets, the more difficult it becomes for the government to pursue independent policy targets. For the case of China, it would be harder for the PBC to stablize the exchange rate and the domestic interest rate simultaneously when the RMB exchange rate becomes more flexible. The PBC, however, can look to the offshore market for information that is relevant for shaping its policy frontier. Second, we gain some insights on the pricing mechanism of NDF. Fundamentally speaking, the pricing of an NDF is based on the same principles as a conventional foreign exchange forward, involving the interest rate differentials between the base and price currencies. However, as the transactions take place offshore without access to local money markets, NDF pricing is driven more by short-term conditions as well as fluctuations in expectations. Prices in the NDF market can be a useful information tool for authorities and investors to gauge market expectations of potential pressures on an exchange rate regime going forward (Lipscomb, 2005). Finally, by focusing on China, the largest emerging economy in the world, our study is not only meaningful for other developing countries with similar exchange rate arrangements and regulatory frameworks for capital flows, but also for the global financial market as the RMB is on the way of becoming a major international currency.

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Table 1. Descriptive statistics for the daily return changes

	Mean	Standard deviation	Skewness
Pre-reform period (4/26/1999-7/20/2005)			
ΔRSPOT	-0.0011	0.8721	-0.3321
ΔRNDF	0.0020	0.9191	0.0499
Early post-reform period (7/21/2005-8/31/2009)			
ΔRSPOT	0.0199	0.4256	2.3885
ΔRNDF	0.0236	0.1564	2.1499
Re-peg period (9/01/2009-6/18/2010)			
ΔRSPOT	-0.0056	0.2604	-0.4427
ΔRNDF	0.0011	0.0571	0.2505
Late post-reform period (6/19/2010-12/31/2012)			
ΔRSPOT	0.0139	0.4957	0.6944
ΔRNDF	0.0157	0.1374	0.3903

Note: ΔRSPOT: daily return change in the onshore spot market, ΔRNDF: daily return change in the offshore NDF market. Both are in percentage points.

Table 2. Estimation results for the GARCH models

	Symmetric		Asymmetric	
	ΔRSPOT	ΔRNDF	ΔRSPOT	ΔRNDF
const	0.0033	0.0002	-0.0069	-0.0007
	(0.0049)	(0.0004)	(0.0053)	(0.0004)
AR(1)	-0.3251*	0.0422*	-0.3218*	0.1074*
	(0.0184)	(0.0130)	(0.0173)	(0.0118)
ω_i	0.0032*	9.11e-06**	0.0027*	1.28e-05**
	(0.0002)	(4.93e-06)	(2.15e-08)	(4.93e-06)
δ_i	0.0982*	0.0992*	0.0032	0.0073*
	(0.0047)	(0.0032)	(0.0041)	(0.0028)
θ_i	0.8943*	0.6378*	0.9127*	0.6316*
	(0.0038)	(0.0039)	(0.0033)	(0.0053)
γ_i			0.1553*	0.6271**
			(0.0106)	(0.0446)
Second-moment condition	0.992	0.737	0.993	0.952
Log-moment condition			-0.023	-0.038

Note: Both estimations include 2654 observations. Numbers in the parentheses are standard errors. * and ** indicate 1% and 10% significance, respectively.

Table 3. Estimation results for the DCC models

	Mean-Reverting DCC		Integrated DCC
	α	β	λ
Symmetric GARCH	0.0060*	0.9905*	0.9932*
	(0.0040)	(0.0052)	(0.0024)
	log likelihood -5063.7		log likelihood -5066.5
	Mean-Reverting DCC		Integrated DCC
	α	β	λ
Asymmetric GARCH	0.0048*	0.9925*	0.9946*
	(0.0026)	(0.0051)	(0.0021)
	log likelihood -5068.7		log likelihood -5071.6

Note: Numbers in the parentheses are standard errors. * indicates 1% significance.

Table 4a. Summary statistics for estimated dynamic conditional correlations between ∆RSPOT and ∆RNDF: Symmetric GARCH

	No. Obs	Mean	Median	Standard deviation
Pre-reform period (4/26/1999 – 7/21/2005)				
Mean-Reverting	1073	0.050	0.059	0.054
Integrated DCC	1073	0.015	0.031	0.079
Early post-reform period (7/21/2005 – 8/31/2009)				
Mean-Reverting	916	0.186	0.193	0.035
Integrated DCC	916	0.219	0.230	0.042
Re-peg period (9/01/2009 – 6/18/2010)				
Mean-Reverting	171	0.094	0.091	0.015
Integrated DCC	171	0.094	0.096	0.021
Late post-reform period (6/19/2010 – 12/31/2012)				
Mean-Reverting	494	0.160	0.162	0.036
Integrated DCC	494	0.187	0.192	0.049

Changes after the reform and equality tests				
	Mean increased	Median increased	t-test (p-value)	Kruskal-Wallis test (p-value)
Mean-Reverting	0.136	0.134	62.5 (0.00)	1336.5 (0.00)
Integrated DCC	0.204	0.199	66.4 (0.00)	1387.4 (0.00)

Note: Changes after the reform refer to the mean and median increases from the pre-reform period to the early post-reform period.

Table 4b. Summary statistics for estimated dynamic conditional correlations between ∆RSPOT and ∆RNDF: Asymmetric GARCH

	No. Obs	Mean	Median	Standard deviation
Pre-reform period (4/26/1999 – 7/21/2005)				
Mean-Reverting	1073	0.051	0.061	0.048
Integrated DCC	1073	0.019	0.039	0.069
Early post-reform period (7/21/2005 – 8/31/2009)				
Mean-Reverting	916	0.183	0.192	0.029
Integrated DCC	916	0.208	0.219	0.039
Re-peg period (9/01/2009 – 6/18/2010)				
Mean-Reverting	171	0.107	0.107	0.012
Integrated DCC	171	0.121	0.126	0.018
Late post-reform period (6/19/2010 – 12/31/2012)				
Mean-Reverting	494	0.154	0.151	0.032
Integrated DCC	494	0.178	0.179	0.040

Changes after the reform and equality tests

	Mean increased	Median increased	t-test (p-value)	Kruskal-Wallis test (p-value)
Mean-Reverting	0.132	0.131	69.5 (0.00)	1393.7 (0.00)
Integrated DCC	0.189	0.180	68.6 (0.00)	1416.2 (0.00)

Note: Changes after the reform refer to the mean and median increases from the pre-reform period to the early post-reform period.

Table 5a. Spillover effect results: Symmetric GARCH

	Pre-reform period		*Early post-reform period*		*Re-peg period*		*Late post-reform period*	
	$r_{i,t}$=ΔRSPOT $r_{j,t}$=ΔRNDF	$r_{i,t}$=ΔRNDF $r_{j,t}$=ΔRSPOT	$r_{i,t}$=ΔRSPOT $r_{j,t}$=ΔRNDF	$r_{i,t}$=ΔRNDF $r_{j,t}$=ΔRSPOT	$r_{i,t}$=ΔRSPOT $r_{j,t}$=ΔRNDF	$r_{i,t}$=ΔRNDF $r_{j,t}$=ΔRSPOT	$r_{i,t}$=ΔRSPOT $r_{j,t}$=ΔRNDF	$r_{i,t}$=ΔRNDF $r_{j,t}$=ΔRSPOT
const	-0.0009	-0.0003	0.0003	0.0066**	-0.0018	0.0001	0.0040	0.0048
	(0.0112)	(0.0002)	(0.0002)	(0.0034)	(0.0037)	(0.0016)	(0.0101)	(0.0041)
AR(1)	-0.3937*	0.0016*	-0.0144**	0.0491	-0.3459*	-0.1489**	-0.1662*	-0.0167
	(0.0286)	(0.0006)	(0.0058)	(0.0302)	(0.0705)	(0.0629)	(0.0420)	(0.0488)
τ_i	0.1713	-0.0658*	0.1195*	0.0134	0.0829	0.0124	0.2294**	0.0271**
	(0.2354)	(0.0077)	(0.0173)	(0.0087)	(0.1938)	(0.0144)	(0.1034)	(0.0096)
ω_i	0.0036*	1.2e-05	0.0432*	0.0156	7.8e-05	-5.5e-06	0.0947*	0.0011**
	(0.0068)	(1.3e-05)	(0.0121)	(0.0117)	(2. 8e-08)	(2.2e-05)	(0.0196)	(0.0005)
δ_i	0.0492	0.2037*	0.3149*	0.1277	0.3329**	0.0784	0.5779***	0.2783*
	(0.0064)	(0.0833)	(0.1038)	(0.1056)	(0.1860)	(0.0595)	(0.1683)	(0.0688)
θ_i	0.9332*	0.7660*	0.3826*	0.5291***	0.6504*	0.9155*	0.3046*	0.6686*
	(0.0073)	(0.0260)	(0.1077)	(0.2869)	(0.1010)	(0.0576)	(0.1051)	(0.0575)
χ_i	0.2189	0.0001*	0.3094	-0.0013	0.6927	0.0025	0.6092	0.0010
	(0.1183)	(7.52e-05)	(0.2940)	(0.0009)	(0.6044)	(0.0017)	(0.5761)	(0.0014)

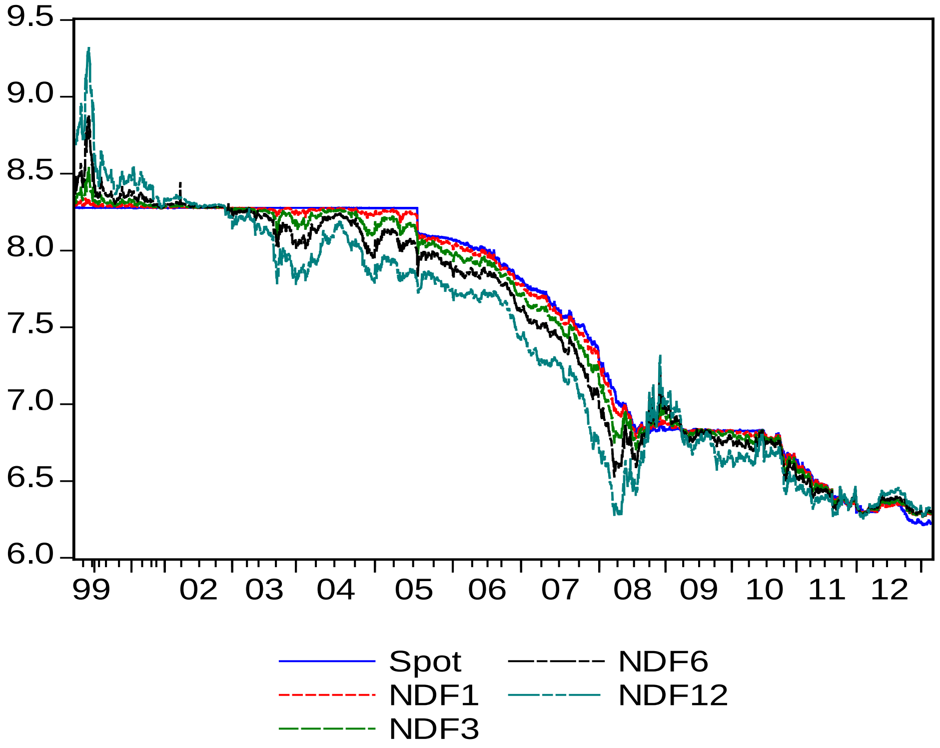
Note: τ_i: mean spillover effect from market *j* to market *i*. χ_i: volatility spillover effect from market *j* to market *i*. Numbers in the parentheses are standard errors. *, **, and *** indicate 1%, 5%, and 10% significance, respectively.

Table 5b. Spillover effect results: Asymmetric GARCH

	Pre-reform period		*Early post-reform period*		*Re-peg period*		*Late post-reform period*	
	$r_{i,t}$=ΔRSPOT $r_{j,t}$=ΔRNDF	$r_{i,t}$=ΔRNDF $r_{j,t}$=ΔRSPOT	$r_{i,t}$=ΔRSPOT $r_{j,t}$=ΔRNDF	$r_{i,t}$=ΔRNDF $r_{j,t}$=ΔRSPOT	$r_{i,t}$=ΔRSPOT $r_{j,t}$=ΔRNDF	$r_{i,t}$=ΔRNDF $r_{j,t}$=ΔRSPOT	$r_{i,t}$=ΔRSPOT $r_{j,t}$=ΔRNDF	$r_{i,t}$=ΔRNDF $r_{j,t}$=ΔRSPOT
const	-0.0161	-0.0002	0.0002	0.0051**	-0.0020	0.0002	-0.0007	0.0035
	(0.0128)	(0.0002)	(0.0019)	(0.0009)	(0.0037)	(0.0016)	(0.0099)	(0.0042)
AR(1)	-0.3909*	0.0016*	-0.0144*	0.0213	-0.3451*	-0.1474**	-0.2083*	-0.0154
	(0.0291)	(0.0004)	(0.0040)	(0.0488)	(0.0706)	(0.0647)	(0.0412)	(0.0485)
τ_i	0.3630	-0.0598*	0.1165*	0.0109	0.0637	0.0127	0.2412**	0.0253*
	(0.2298)	(0.0094)	(0.0173)	(0.0210)	(0.1860)	(0.0144)	(0.1005)	(0.0095)
ω_i	0.0035*	1.2e-05	0.0031**	0.0147	8.7e-05	-4.3e-06	0.0617*	0.0011**
	(0.0007)	(1.3e-05)	(0.0012)	(0.0009)	(0.0003)	(1.9e-05)	(0.0189)	(0.0005)
δ_i	0.0165***	0.2016*	-0.0554*	0.1110**	0.3063	0.0811	0.2616**	0.1925*
	(0.0098)	(0.0880)	(0.0121)	(0.0495)	(0.2443)	(0.0825)	(0.1420)	(0.0680)
γ_i	0.0552*	-0.1575	0.1346**	0.0955	0.1130	-0.0806	0.4740***	0.1647
	(0.0175)	(0.1117)	(0.0501)	(0.0617)	(0.3682)	(0.0992)	(0.2631)	(0.1182)
θ_i	0.9366*	0.7591*	0.9065*	0.5049*	0.6423*	0.9187*	0.2981**	0.6859*
	(0.0072)	(0.0260)	(0.0186)	(0.0376)	(0.1010)	(0.0541)	(0.1492)	(0.0592)
χ_i	0.1967	0.0001**	0.0956***	-0.0012	0.5356	0.0022	0.3693	0.0009
	(0.1176)	(7.5e-05)	(0.0548)	(0.0014)	(0.5275)	(0.0016)	(0.4026)	(0.0013)

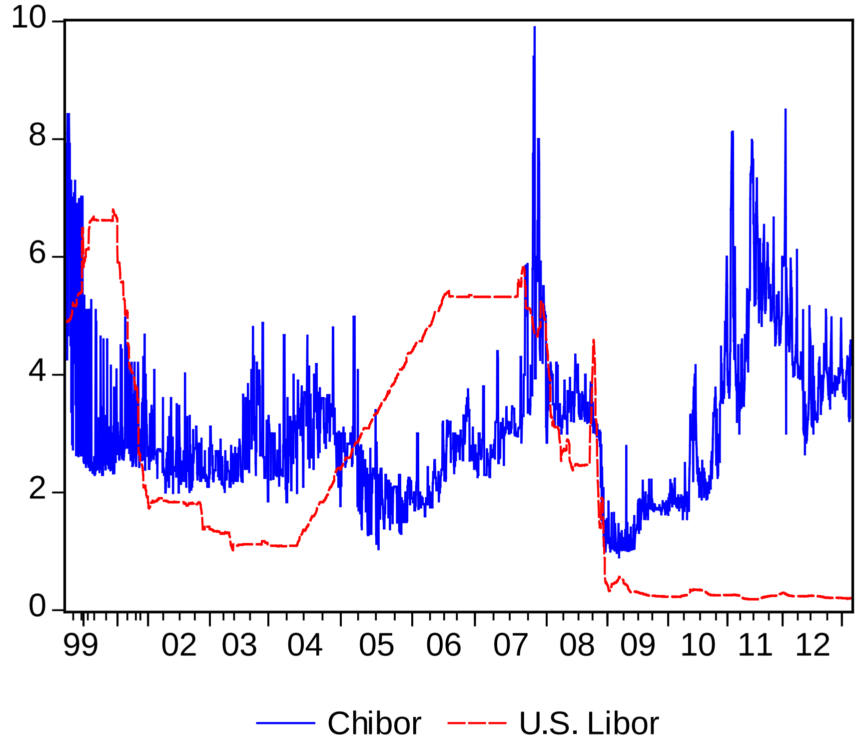
Note: τ_i: mean spillover effect from market j to market i. χ_i: volatility spillover effect from market j to market i. Numbers in the parentheses are standard errors. *, **, and *** indicate 1%, 5%, and 10% significance, respectively.

Figure 1. The RMB spot exchange rate and NDF rates



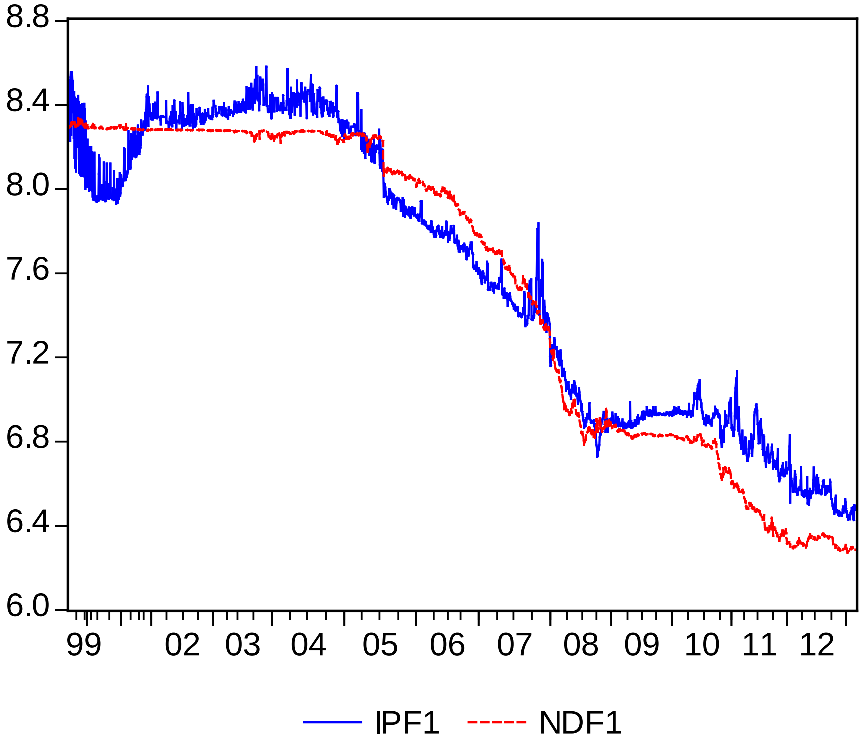
Note: Spot: Yuan/US Dollar spot exchange rate, NDF1: 1-month NDF rate, NDF3: 3-month NDF rate, so on.

Figure 2. The interbank rates for the RMB and USD



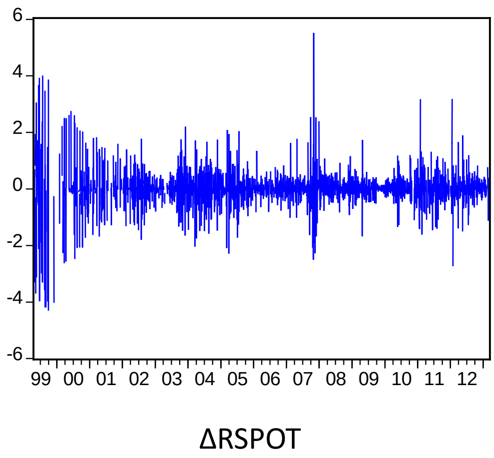
Note: Both rates are for the one-month maturity and are in percent per annum.

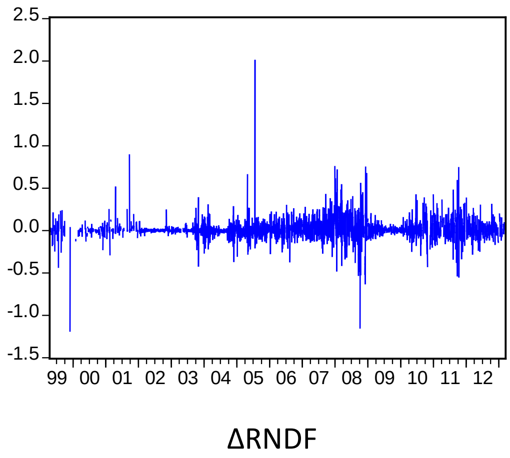
Figure 3. Implied 1-month forward rate and the actual 1-month NDF rate



Note: NDF1: actual 1-month NDF rate, IPF1: implied 1-month forward rate.

Figure 4. Daily return changes in the RMB onshore and offshore markets





Note: ΔRSPOT: daily return change in the onshore market, ΔRNDF: daily return change in the offshore market.

Figure 5a. Dynamic conditional correlations between the onshore and offshore markets: Symmetric GARCH

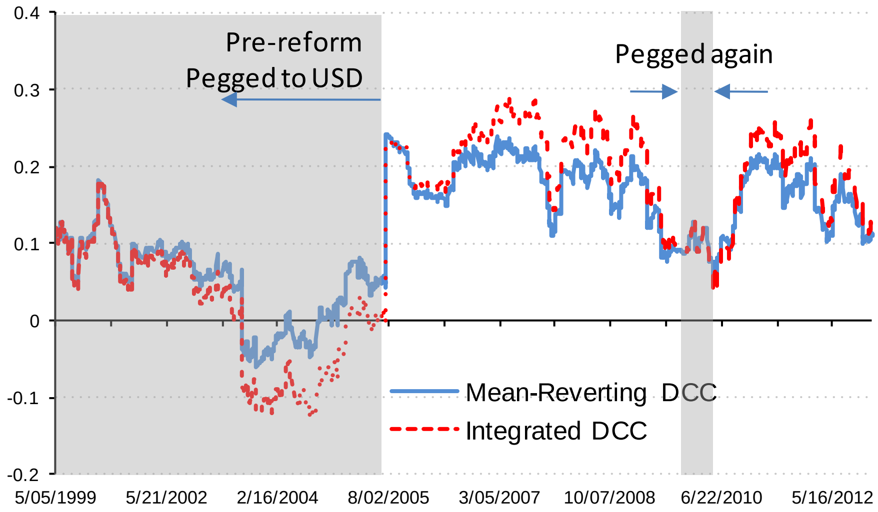


Figure 5b. Dynamic conditional correlations between the onshore and offshore markets: Asymmetric GARCH