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## Volatility transmission and volatility impulse response functions in the main and the satellite Renminbi exchange rate markets

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Michael Funke, Julius Loermann and  
Andrew Tsang

Volatility transmission and volatility  
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Suomen Pankki  
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Michael Funke, Julius Loermann and Andrew Tsang

# Volatility transmission and volatility impulse response functions in the main and the satellite Renminbi exchange rate markets

## Abstract

We analyse volatility spillovers between the on- and offshore (CNY and CNH) Renminbi exchange rates towards the US dollar (USD). The volatility impulse response (VIRF) methodology introduced by Hafner and Herwatz (2006) is applied to several shocks between January 2012 and December 2019. Furthermore, we propose a novel way of estimating VIRFs based on Bayesian estimation of the MV-GARCH BEKK model. A simple Independence Chain Metropolis-Hastings algorithm allows drawing VIRFs in an efficient manner, allowing to analyse the significance and persistence of volatility shocks and associated volatility spillovers. The VIRF results show that the CNH exchange rate promptly reflects the global market demand and supply, while the CNY exchange rate reacts with a time lag. The VIRF results also show the existence of spillovers between the two markets as the co-volatility increases in response to shocks.

**Keywords:** Renminbi, volatility spillovers, volatility impulse responses, Bayesian estimation, multivariate GARCH models

**JEL-Classification:** C32, E58, F31, F51

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# 1 Introduction

The Renminbi (RMB) has witnessed an increasing influence worldwide, paralleling the ascendancy of China as the second economic powerhouse. According to the “Triennial Central Bank Survey of Foreign Exchange Turnover”, released by the Bank for International Settlements in April 2019 (<https://www.bis.org/statistics/rpfx19.htm>), the RMB has become the world’s 8<sup>th</sup> most actively traded currency. The average daily RMB turnover more than doubled, from US dollar (USD) 120 billion to USD 284 billion, between April 2013 and April 2019, representing a rise in the share in global FX turnover from 2.2 percent to 4.3 percent. 95 percent of renminbi turnover is due to trading against the USD. With the RMB entering the IMF’s Special Drawing Rights (SDR) basket in November 2016, China’s transforming exchange rate arrangement has received an even greater international nod.

In this paper, we focus on one currency traded in two separate markets. The RMB traded onshore has the trading symbol CNY, while the RMB traded offshore has the trading symbol CNH. Therefore, both the CNY rate and CNH rate constitute the pricing of RMB, but in different markets. Similar to other major currencies, a large share of RMB (64%) is traded in the offshore market, mirroring the importance of trade finance and foreign investment in China.<sup>1</sup> According to the law of one price, if there are no capital constraints and other market frictions, the rates would be expected to be the same. However, in contrast to the CNH exchange rate that is determined mainly by market forces, the CNY market remains highly regulated. The People’s Bank of China (PBoC) has a presence in the market in order to maintain exchange rate stability, notwithstanding increased flexibility in the CNY exchange rate in recent years.<sup>2</sup> Against this background, RMB is a prime example for examining to what extent a single currency could have different responses to news and market risks in different markets.

Assessing the different responses of RMB to the shocks in different markets, this paper employs the volatility impulse response function (VIRF) analysis using the MV-GARCH-BEKK model, introduced by Hafner and Herwatz (2006). Specifically, this paper compares and contrasts how the main and the satellite RMB exchange rates respond to shocks originating from exchange rate policy, financial market turbulences and the US-China trade conflict in 2018 – 2019 which is sometimes referred to as the US-China trade war. In addition, this paper presents a novel Bayesian estimation method via a Markov Chain Monte Carlo (MCMC) algorithm to construct confidence bands for the VIRF. In Bayesian estimation, a credible interval can be generated by deriving the

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<sup>1</sup> Most of the major currencies (except British pound) have more than 60% off-shore trading. According the latest transaction figures in BIS (2019), the off-shore trading share of the top seven largest trading currencies are US dollar (79%), euro (84%), Japanese yen (74%), British pound (30%), Australian dollar (87%), Canadian dollar (82%) and Swiss franc (72%).

<sup>2</sup> See also IMF (2013, Box 2, p. 16) for an attempt at synthesising the debate on onshore and offshore RMB markets.

quantiles of the posterior distribution of either the model's parameters or of a function of these. In our framework, it serves the same purpose as a confidence interval. Hence, the term confidence interval (band) is used. An uninformative prior in combination with an Independence Chain Metropolis Hastings (ICMH) algorithm allows to draw data driven VIRFs and confidence bands, permitting to judge the significance and persistence of shocks on exchange rate volatility. Furthermore, the size and persistence of the volatility spillover between the two markets can be analysed by investigating the covariance trajectory.

This paper contributes to the literature in two ways. First, this paper extends the VIRF methodology by implementing a Bayesian estimation framework, allowing to calculate confidence bands. To our knowledge, this is the first paper applying this estimation approach for VIRFs. Previous work using VIRFs has calculated only impulse responses without confidence bands (see, e.g., Lin, 1997, Hafner and Herwatz, 2006, Arouri et al., 2012, Eraslan and Ali, 2018, Gabauer, 2020, Jin et al., 2012, Jin, 2015, and Le Pen and Sévi, 2010). Second, this paper also contributes to the literature of the RMB exchange rate. Although previous studies have studied the lead-lag structure and the existence of spillovers between the two exchange rate markets, they do not examine how the main and the satellite RMB exchange rates respond to shocks.<sup>3</sup> To fill this gap, this paper shows the different dynamics of volatilities and co-volatilities between CNY and CNH markets by investigating the trajectories of these variables over time. Furthermore, this paper also provides evidence supporting the notion that the CNH market can serve for RMB internationalisation by effectively reflecting global market demand and supply, while the offshore market information transmits time-delayed to the onshore market (Cheung *et al.*, 2018 and Chen, 2019). The following two questions are of particular interest. First, given the different institutional frameworks, how do both exchange rates react to the same shocks? Second, how strong and persistent is the risk spillover between both distinct markets?

The remainder of the paper is organised as follows. Section 2 briefly reviews the institutional arrangements of the main and the satellite RMB markets, and the exchange rate data used in this paper. Section 3 discusses the novel methodology of constructing the volatility impulse response functions, and Section 4 reports the estimation results. Section 5 concludes.

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<sup>3</sup> Chen (2019) suggests that the CNH market has an informational advantage, while the information transmission to the CNY market has been improved after the 2015 Reform on the CNY fixing mechanism. Maziad and Kang (2012), Owyong *et al.* (2015) and Xu *et al.* (2017) suggest that different informational advantages occur between the two markets in different sample periods. Leung and Fu (2014) and Wang and Wang (2017) provide evidence for the existence of volatility spillovers between the two markets. Funke *et al.* (2015) suggest that the price differential between the two markets can be explained by the economic fundamentals and policies.

## 2 Institutional background and data for RMB exchange rates

The motivation for this section is the belief that in studying this issue, it is important to understand the relevant institutional details. The comparability of data relating to the trading hour must also be ensured.

### 2.1 Institutional background

The CNY market still remains highly regulated. Access to the wholesale market is restricted to domestic entities including banks, finance companies (subsidiaries of large SOEs), and subsidiaries of foreign banks. At the retail level, each individual can exchange foreign currencies within the annual limit of USD 50,000 per year. Importantly, foreign exchange transactions between banks and their customers are required to be backed by allowed current account or capital account transactions, and pure speculative trades are prohibited.

At present, China officially maintains a managed floating exchange rate arrangement.<sup>4</sup> China started to adopt a managed floating system in the year 2005. During the global financial crisis, the CNY was temporarily fixed against the USD. In June 2010, the PBoC returned to the managed floating exchange rate regime. Also, China gradually widened the trading band around the daily USD fixing from an initial  $\pm 0.3\%$  from 1 January 1994 to  $\pm 0.5\%$  on 21 May 2007, to  $\pm 1.0\%$  on 16 April 2012, and finally to  $\pm 2.0\%$  on 17 March 2014. The widening of the band was aimed at increasing the role of market forces, in the context of the long-term policy goal of gradually increasing exchange rate flexibility.

Another important policy change concerns the fixation of the central parity. On 11 August 2015, the PBoC announced a highly important step to making the exchange rate system more market-based. Under the new fixing design, commercial banks were asked to submit quotes that took account of the closing spot rate of the previous day as well as market supply and demand.<sup>5</sup> The discretion in setting the fixing should serve to prevent or limit self-sustaining drifts in expectations. In addition to this, China Foreign Exchange Trade System (CFETS) started publishing an RMB effective exchange rate index, the so-called CFETS basket in December 2015. In addition to the CFETS index, the PBoC in late 2015 started also to publish two further indices based on BIS and SDR baskets and directed banks to use all of these indices when submitting their daily central parity quotes (<http://www.pbc.gov.cn/en/3688110/3688172/4048320/3712490/index.html>). The launch of

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<sup>4</sup> According to the IMF's de facto exchange rate regime classification, the RMB is classified as managed floating (or specifically, having a crawl-like arrangement, see Das, 2019 and IMF, 2019).

<sup>5</sup> An implication of this change is that the economic exchange rate regime may be "self-referential" in the sense of Marcat and Sargent (1989). Beliefs affect the RMB data-generating process, which in turn affects the fixing and thus future beliefs. As expectation errors are propagated throughout the economy, they become partially self-fulfilling, opening the door to instability.



the CFETS index does not necessarily imply the immediate adoption of a basket peg, but it may perhaps signify the PBoC's intention to move in that direction in the future.

Since the fixing reform, the CNY has been in the midst of a difficult transition from a highly managed foreign exchange regime to a more floating one. One of the problems encountered during the transition was an increase in capital outflows both from residents and non-residents. In response, in February 2016, China formulated new guidance to banks for their daily quotes for the RMB/USD fixing.<sup>6</sup> Henceforth, the quotes were based on the “previous closing rate plus overnight changes in a currency basket”, with the “changes in a currency basket” referring to the adjustment in the CNY/USD rate needed to offset the impact of changes in cross-rates among basket currencies.

On 26 May 2017, the PBoC announced another amendment of the daily fixing at the start of the trading day. The new method combines the previous arrangement with a countercyclical adjustment factor (McCauley and Shu, 2019). Officials said that the move was intended to deal with overreaction of markets driven by herding behaviour. Adding a vague countercyclical factor with the objective of reducing “irrational” depreciation expectations and “pro-cyclical” herding behaviour makes it more difficult to assess the situation. Apparently, this reform increased the flexibility of the Chinese authorities to affect exchange rate trends. China used this room for manoeuvre several times. In June 2017, for example, the Chinese authorities engineered a stronger RMB fixing to ensure that there was no pick-up in capital outflows. Yet at the same time, it must be emphasised that this sentiment-boosting move in accordance with the saying “two steps forward and one back”, is no fundamental revamp of China's exchange rate regime. The back and forth regarding the countercyclical factor was not over yet. On 9 January 2018, the PBoC revamped the regulatory regime again. Under the updated PBoC guidance, banks that participate in setting the daily fixing rate no longer need to include the countercyclical factor which according to market participants has supported the CNY's external value.<sup>7</sup> Finally, PBoC reintroduced the countercyclical factor into the CNY fixing mechanism again on 24 August 2018 to support the RMB exchange rate, which was weakened due to the trade tensions with the US.<sup>8</sup>

A remarkable final turnaround then took place on 5 August 2019 in apparent retaliation to the threat of new import tariffs on the remainder of Chinese imports. The RMB weakened, passing the psychologically significant mark of seven RMB to the USD, the lowest point for the Chinese

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<sup>6</sup> Introducing a flexible exchange rate is an important part of the Chinese financial liberalisation programme. On the other hand, as ever, China's willingness to trust market forces extends only so far. Almost everything China has done since market reforms started in the late 1970s has involved gradualism. The experience from the 30 years under Chairman Mao was that “big leaps” caused severe disruptions in the economy. Therefore, the Chinese authorities want to hold on to a certain amount of control and thus continue to have a policy of avoiding disruptive FX moves. In brief, the policy approach can be formulated as “hate to fix but fear to float” (see <http://www.cf40.org.cn/html/RESEARCH-REPORTS/201712/11-12420.html>).

<sup>7</sup> See <https://www.bloomberg.com/news/articles/2018-01-09/china-is-said-to-shift-way-it-manages-yuan-after-currency-s-jump>.

<sup>8</sup> See <https://www.bloomberg.com/news/articles/2018-08-24/china-resumes-counter-cyclical-factor-in-yuan-fixing>.

currency since the global financial crisis. Market participants were largely caught off-guard as the psychological barrier was broken. The financial markets interpreted the RMB devaluation as a signal that the Chinese authorities are prepared to wield its currency as a tool amid a widening trade conflict with the US.

In a nutshell, China's present exchange rate regime resembles a staircase-shaped target zone exchange rate system. This looks like a special case of Krugman's (1991) target zone model. In the original target zone exchange rate model, the central parity is fixed and two confidence bands exist. In the Chinese case, the central parity is changed every day (with certain nuances the morning fix is dependent on market prices on the previous day, i.e., the central parity of the CNY is closely pegged to the closing price in the previous trading day). This regular course is additionally overshadowed by occasional parity changes driven by economic policy concerns. Taken together, one could describe the CNY exchange rate regime as a "moving Krugman band system" that is unique across the world.

In contrast, the CNH is a flexible exchange rate determined by market forces. Spot trading in the CNH market became active in August 2010 following the launch of a cross-border renminbi trade settlement, and deliverable forwards and derivatives developed subsequently. The decisive policy shift behind the rapid growth in the CNH market was the Chinese programme to accelerate the use of the RMB as an invoicing and settlement medium for trade. CNH does not have restrictions on the participants (both wholesale and retail levels) and there are no limits on trading. The CNH exchange rate can be freely traded globally for 24 hours every trading day, without reference to the CNY fixing rate. Hence, no trading band is applied to the CNH. At least officially, neither the People's Bank of China (PBoC) nor the Hong Kong Monetary Authority (HKMA) intervene in the CNH market, enabling the offshore RMB exchange rate to reflect global demand and supply.<sup>9</sup>

## 2.2 Data

In order to calculate the VIRFs, daily CNH and CNY series downloaded from Bloomberg are used in this study. Attention must be paid to the fact that both exchange rates are traded during different time slots. Specifically, the onshore CNY market trades between 09:30 and 23:30 Beijing time, while the closing rate of 24-hour-traded off-shore CNH is recorded at 17:00 New York time (close

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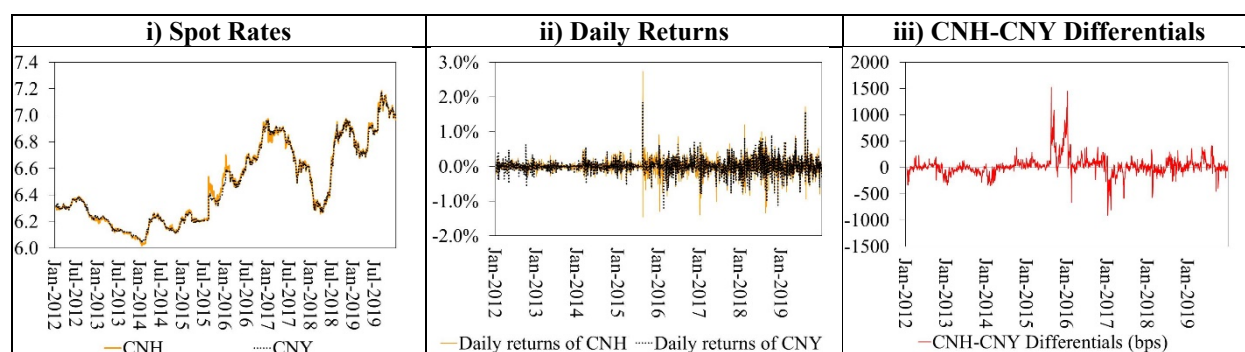
<sup>9</sup> There are only a few suspected and unconfirmed cases of indirect mainland Chinese interventions in the off-shore market. A frequently cited example is 11 January 2016. In Hong Kong, a subsidiary of a Chinese state-owned bank, Bank of China (Hong Kong) is the sole clearing bank for RMB business in Hong Kong. This sole RMB clearing bank (RMB liquidity provider) status is assigned by HKMA. On 11 January 2016, the Bank of China (Hong Kong) did not provide the funding in the market, which market participants interpreted as an intervention in the CNH market by Chinese authorities (see <https://ftalphaville.ft.com/2016/01/12/2149849/cnh-hibor-nothing-to-see-here>). A more evident influence of the PBoC on the satellite market takes place via mandatory reserve holdings on CNH holding of mainland banks. For example in 2016, the PBoC imposed a 20% reserve requirement on CNH holdings in order to calm currency speculation. The rate was lowered back to zero in September 2017, but raised again to 20% in August 2018 (see <https://www.scmp.com/business/companies/article/2158083/chinas-yuan-falls-15-month-low-trade-war-escalates>).

of the New York market), i.e. 5.5 hours (05:00 Beijing time of the next day during summer) or 6.5 hours (06:00 during winter) after the CNY closed.<sup>10</sup>

The exchange rates at different closing times have a different information content. The different trading hours imply a different information content of the main and the satellite exchange rate. For example, if a shock occurs in the afternoon of the New York time, i.e., after CNY closed but before the closing time of CNH, the impact of the shock could be reflected in the two exchange rates on different dates. To avoid these problems, we match both exchange rates at the closing time of the onshore market, using half-hourly exchange rates quotes from Bloomberg.<sup>11</sup> The log-differenced series are used due to the stationarity issue. The sample period is from 11 January 2012 to 31 December 2019.

In this paper, the analysis will focus on the spot rate. Figure 1 shows the spot rates, daily returns and the CNH-CNY differentials (in basis points) during the sample period. The sharp spike with substantial CNH premium occurred during and shortly after the 2015 reform. The volatilities of the exchange rates in the post-reform era are higher than those in the pre-reform period, and in particular, the volatilities became higher following the US-China trade conflict starting from 2018. Therefore, in the VIRF analysis, we will select the shocks of exchange rate policy changes, market turbulences and the shocks related to the US-China trade conflict. A detailed analysis of the shocks is provided in Section 4.2.

Figure 1 RMB exchange rates



Notes: The charts show the daily spot rates for USD/CNH and USD/CNY, daily returns and CNH-CNY differentials (in basis points) from 11 Jan 2012 to 31 Dec 2019. Before 2016, the daily rates are the exchange rates at 16:30 Beijing time, while they are the exchange rates at 23:30 Beijing time from 2016. The summary statistics for the returns of the RMB spot rates:

	$\Delta \ln(\text{CNH})$	$\Delta \ln(\text{CNY})$
Mean	0.005	0.005
Variance	0.054	0.037
Covariance	0.037	
Correlation	0.815	

Source: Bloomberg.

<sup>10</sup> Before 2016, the CNY market closed at 16:30.

<sup>11</sup> At the beginning of our sample period, Bloomberg quotations showed some missing half-hourly values. In these cases, we have used the most recent 30 minute quote available.

### 3 Econometric methodology

We now turn to a brief description of our econometric framework conceptualising volatility shocks and volatility spillovers.

#### 3.1 Multivariate GARCH: The BEKK model

In our analysis, we apply a bivariate GARCH(1,1)-BEKK model, introduced by Engle and Kroner (1995), to model the conditional covariance matrix between the filtered returns of the USD/CNH and USD/CNY exchange rates.<sup>12</sup> The dynamics of the conditional covariance matrix are given by

$$\mathbf{H}_t = \mathbf{C}'\mathbf{C} + \mathbf{A}'\boldsymbol{\epsilon}_{t-1}\boldsymbol{\epsilon}'_{t-1}\mathbf{A} + \mathbf{G}'\mathbf{H}_{t-1}\mathbf{G}, \quad (1)$$

where  $\mathbf{C}$  is a 2x2 lower triangular matrix and  $\mathbf{A}$  and  $\mathbf{G}$  are 2x2 parameter matrices. The assumed distribution of the *iid* error process  $\boldsymbol{\epsilon}_{t-1}$  is a standard normal distribution. The BEKK model is able to account for conditional heteroscedasticity in each series separately, while at the same time allowing for volatility spillovers, measured by the conditional covariance between the two exchange rates. In contrast to the VECH model of Bollerslev *et al.* (1988), the BEKK model does not suffer from potentially negative definite covariance matrices, as the quadratic form implied by the matrices  $\mathbf{A}$  and  $\mathbf{G}$  ensures positive definiteness.

#### 3.2 Volatility impulse response functions and identification

Hafner and Herwatz (2006) introduce the concept of volatility impulse response functions (VIRFs). Based upon Koop *et al.* (1996), a VIRF is given by the expected evolution of volatilities and co-volatilities when a structural shock  $\mathbf{v}_0$  is induced, minus the expected evolution of volatilities and co-volatilities when such a shock is absent. The evolution of the volatility profile in its most general form is therefore given by

$$\boldsymbol{\psi}_t = E[\text{vech}(\mathbf{H}_t)|\mathbf{v}_0, \Omega_{t-1}] - E[\text{vech}(\mathbf{H}_t)|\Omega_{t-1}], \quad (2)$$

where  $\boldsymbol{\psi}_t = [\sigma_{11}^2, \sigma_{12}, \sigma_{22}^2]'$  is the vector of responses of the conditional variances and the covariance of the two exchange rates. The VECH operator,  $\text{vech}(\cdot)$ , stacks the lower triangular part of a symmetric  $N \times N$  matrix into an  $N^* = N(N + 1)/2$  vector. The information set available at  $t$  is denoted by  $\Omega_{t-1}$  (i.e., given information until date  $t - 1$ ), while  $\mathbf{v}_0$  is a structural shock vector, specified as  $\mathbf{v}_0 = \mathbf{H}_0^{-0.5}\boldsymbol{\epsilon}_0$ .

<sup>12</sup> To reduce the number of parameters in the estimation of the GARCH(1,1)-BEKK model, we pre-filter the returns of the USD/CNH and USD/CNY exchange rate by applying a bivariate VAR( $p$ ) model, whose lag-length of 11 has been selected by AIC in this paper. For the estimation of the BEKK model, the residuals of the VAR(11) are used, such that the mean equation of the BEKK model only contains an intercept.

Although the original nonlinear impulse response functions of Koop *et al.* (1996) were derived via bootstrap simulations, Hafner and Herwatz (2006) demonstrated that there exist closed-form solutions for the VIRFs at any horizon whenever the MV-GARCH model can be transformed into a VECH form.<sup>13</sup> The initial response for the BEKK model, described in (1) is then given by

$$\boldsymbol{\psi}_1 = \mathbf{A}^*[\text{vech}(\boldsymbol{\epsilon}_0\boldsymbol{\epsilon}'_0) - \text{vech}(\mathbf{H}_0)], \quad (3)$$

where  $\mathbf{A}^*$  represents the parameter matrix of the equivalent VECH representation for the  $\text{vech}(\boldsymbol{\epsilon}_{t-1}\boldsymbol{\epsilon}'_{t-1})$  part. For any  $t \geq 2$ , the response vector is given by the following recursion

$$\boldsymbol{\psi}_t = [\mathbf{A}^* + \mathbf{G}^*]\boldsymbol{\psi}_{t-1}, \quad (4)$$

with  $\mathbf{G}^*$  being the parameter matrix of the equivalent VECH representation for the  $\text{vech}(\mathbf{H}_{t-1})$  part. It is worth mentioning that although there exists an analytical solution to the VIRF, they can still be interpreted as a simulation of the volatility profile given the information set up to a specific date  $t - 1$ . The evolution of the VIRF should not be confused with the actual evolution of the volatility profile. Rather the VIRF evolution has to be interpreted as the dynamics of the volatility profile in a world where no new information enters the market, making it a simulation of what the volatility would have been given information until date  $t - 1$ .

Conventional impulse response functions (e.g., Sims, 1980) need an identification scheme that orthogonalises shocks and therefore transforms reduced-form residuals into structural residuals. In contrast, Hafner and Herwatz (2006) have demonstrated that if the standardised residuals resulting from the MV-GARCH model are non-normally *iid* distributed, then the daily shocks (residuals) are structural. Typically, the standardised residuals of a standard daily financial time series are *iid* and non-normally distributed. In other words, a correctly specified MV-GARCH model can identify the above VIRFs and therefore makes them structural. We are going to verify these assumptions on standardised residuals via a single and joint autocorrelation analysis by applying the Ljung-Box-Q-, Hosking-tests and normality analysis by using the Jarque-Bera test.

### 3.3 Bayesian estimation

One novelty of this paper is the estimation procedure of the BEKK model. The usual practice is to use the quasi-maximum likelihood (QML) approach, where the error process  $\boldsymbol{\epsilon}_t$  is assumed to follow

<sup>13</sup> Given (1), the equivalent VECH representation of the BEKK model would correspond to  $\text{vech}(\mathbf{H}_t) = \text{vech}(\mathbf{C}\mathbf{C}') + \mathbf{D}_N^+(\mathbf{A} \otimes \mathbf{A})\mathbf{D}_N\text{vech}(\boldsymbol{\epsilon}_{t-1}\boldsymbol{\epsilon}'_{t-1}) + \mathbf{D}_N^+(\mathbf{G} \otimes \mathbf{G})'\mathbf{D}_N\text{vech}(\mathbf{H}_{t-1})$ , where  $\mathbf{D}_N$  is a duplication matrix, with the property  $\text{vec}(\mathbf{A}) = \mathbf{D}_N\text{vech}(\mathbf{A})$ . Moreover,  $\mathbf{D}_N^+$  is the generalised inverse of the duplication matrix, defined as  $\mathbf{D}_N^+ = (\mathbf{D}_N'\mathbf{D}_N)^{-1}\mathbf{D}_N'$ . To simplify notation the model can be written as  $\text{vech}(\mathbf{H}_t) = \text{vech}(\mathbf{C}\mathbf{C}') + \mathbf{A}^*\text{vech}(\boldsymbol{\epsilon}_{t-1}\boldsymbol{\epsilon}'_{t-1}) + \mathbf{G}^*\text{vech}(\mathbf{H}_{t-1})$ , with  $\mathbf{A}^* = \mathbf{D}_N^+(\mathbf{A} \otimes \mathbf{A})\mathbf{D}_N$  and  $\mathbf{G}^* = \mathbf{D}_N^+(\mathbf{G} \otimes \mathbf{G})'\mathbf{D}_N$ .

either a multivariate normal distribution, a  $t$ -distribution or a generalised error distribution. The obvious disadvantage of the QML procedure is that no confidence intervals can be calculated. That makes it impossible to gauge whether shocks have significant effects on volatilities and co-volatilities and how persistent a shock actually is. To overcome this drawback, we employ a novel Bayesian estimation framework. Specifically, we apply an independence chain Metropolis-Hastings algorithm (ICMH), which belongs to the class of Markov Chain Monte Carlo Methods (MCMC). Bayesian estimation techniques require the specification of a prior distribution and therefore are prone to critique. We meet this criticism by using an uninformative prior, such that the estimation is solely data driven. The uninformative prior approach yields that the posterior mean of the estimated coefficients is equal to QML estimates, making the point estimate of our Bayesian VIRF equal to the QML estimates, while at the same time enabling us to derive confidence bands, which reflect the uncertainty of the VIRF. This paper uses the following ICMH algorithm, which comprises the following steps (see, e.g. Koop, 2003):

1. Initialise the MCMC algorithm with the QML estimates, denoted by the vector  $\boldsymbol{\theta}^{(0)}$ .
2. Draw the coefficients of the BEKK model, denoted by  $\boldsymbol{\theta}^*$ , jointly from a multivariate  $t$ -distribution,  $t(\eta, \boldsymbol{\Sigma})$ , where  $\eta$  are the degrees of freedom and  $\boldsymbol{\Sigma}$  is a positive definite shape matrix.<sup>14</sup> We choose  $\eta = 1$  and  $\boldsymbol{\Sigma} = \mathbf{1}\boldsymbol{\Xi}$ , where  $\boldsymbol{\Xi}$  is the Cholesky decomposition of the QML estimate of the covariance matrix of the estimated BEKK coefficients, to get an acceptance rate between 40% and 50%. The acceptance rate is the ratio between the number of accepted draws and the total number of draws.
3. Calculate the acceptance probability  $\alpha(\boldsymbol{\theta}^{(s-1)}, \boldsymbol{\theta} = \boldsymbol{\theta}^*) = \min\left[\frac{p(\boldsymbol{\theta}=\boldsymbol{\theta}^*)}{p(\boldsymbol{\theta}=\boldsymbol{\theta}^{(s-1)})}, 1\right]$ , where  $\boldsymbol{\theta}^{(s-1)}$  is the previous iterations draw and  $p(\cdot)$  is the likelihood function evaluated at the draws.<sup>15</sup> For simplicity we assume a normal distribution, however using a  $t$ -distribution or GED-distribution yield similar results, which are available upon request.
4. Set  $\boldsymbol{\theta}^{(s)} = \boldsymbol{\theta}^*$  with probability  $\alpha(\boldsymbol{\theta}^{(s-1)}, \boldsymbol{\theta} = \boldsymbol{\theta}^*)$  and set  $\boldsymbol{\theta}^{(s)} = \boldsymbol{\theta}^{(s-1)}$  with probability  $1 - \alpha(\boldsymbol{\theta}^{(s-1)}, \boldsymbol{\theta} = \boldsymbol{\theta}^*)$ .
5. Repeat step 2 to 4  $N = 20,000$  times and discard the first  $B = 10,000$  samples as burn-in replications to assure convergence of the Markov chain.
6. After the burn-in periods, save the coefficient draws  $\boldsymbol{\theta}^{(s)}$ , then draw the VIRFs by applying (3) and (4) and save these draws as well.

<sup>14</sup> These are hyperparameters that can be used to fine tune the acceptance rate of the ICMH algorithm. Koop (2003) suggests using values that result in an acceptance rate of 40-50%. Note, however, that these values are not to be confused with prior-hyperparameters, as our framework keeps the prior uninformative.

<sup>15</sup> If the prior would be informative, one would have to use the posterior instead of the likelihood within the acceptance probability calculation.

7. Calculate *the* posterior means of the VIRFs for each horizon  $h$ , to get the point estimate. Then calculate the 90% confidence interval based on 10,000 posterior draws by using the 0.05 and 0.95 quantiles of the VIRFs' posterior. The acceptance rate is finally calculated as the ratio between the accepted number of draws and the total number of draws.

To check the convergence of the ICMH sampler, we analyse trace plots and the Gelman and Rubin (1992) convergence diagnostic, with three independent Markov chains on the drawn BEKK coefficients. In addition, we access the posterior distributions, and ACFs of the coefficient draws. All convergence graphs can be found in Appendix A.

## 4 Estimation results

### 4.1 Posterior summary statistics, convergence – and model diagnostics

Panel A in Table 1 summarises the posteriors for the coefficients of the bivariate BEKK model described in (1). Plots of histograms of the posterior draws for each coefficient can be found in Figure A1 in the appendix. The model is estimated on the filtered returns of the CNH and CNY exchange rates. All ARCH and GARCH coefficients in the variance-covariance equations are significant at the 1% level, indicating the presence of strong ARCH and GARCH effects. Similar to the previous literature (e.g., Leung and Fu, 2014, and Ho *et al.*, 2018), there are positive and significant bi-directional spillover effects in volatility between CNH and CNY. Specifically, the effect of past CNY volatilities on the CNH volatility is larger than the impact of past CNH volatilities on the CNY volatility. The covariance of both exchange rates increases with the variance of both exchange rates, while the covariance is more sensitive to the changes in CNY volatilities.<sup>16</sup> The estimated results are consistent with the different exchange rate regimes. In particular, the greater volatility of the CNH exchange rate due to the flexible exchange rate regime is evident.

The numerical standard error (NSE) is an accurate diagnostic for MCMC methods. It measures the approximation error of the posterior. The more draws have been taken, the smaller the approximation error will be. For all BEKK coefficients, the NSE is reasonably close to zero, indicating that 20,000 draws from which 10,000 count as burn-in samples are enough to create a reasonable degree of approximation precision. The trace plots, presented in Figure A2 in the appendix wiggle around their posterior mean, without showing high persistence. The acceptance rate is also in the range of 40–50%, which is suggested by Koop (2003). The autocorrelation of the posterior

<sup>16</sup> Compared to the CNH exchange rate, an increase in the CNY exchange rate volatility has a larger impact on the covariance of the two exchange rates, as  $G_{21}G_{22}(0.0659)$  is larger than  $G_{11}G_{12}(0.0235)$ . Moreover,  $G_{11}G_{21}(0.0627)$  is larger than  $G_{12}G_{22}(0.0247)$ . This indicates that an increase in the covariance will increase the CNH volatility over-proportionally.

draws, presented in Figure A3 in the appendix, decline fast within five iterations. Together with the acceptance rate of 44.84%, this indicates that the ICMH algorithm mixes well over the parameter space. The Gelman-Rubin diagnostic is for all coefficients below the critical value of 1.2, indicating that the Markov Chain implied by the ICMH algorithm has converged (Figure A4 in the appendix).

Panel B summarises the model diagnostics for the BEKK model, which is evaluated at the posterior mean of the coefficients presented in Panel A. The individual LB-Q diagnostic, which is calculated for the individual standardised residuals of the two BEKK equations, indicate that there is no joint serial correlation within the first 50 autocorrelations. Moreover, the multivariate test of Hosking (1981), which accounts for joint serial correlation as well as for correlation between the two residual series, also does not find any evidence for the remaining serial correlation. Therefore, the BEKK model is correctly specified to describe the joint volatility dynamics between the CNH and CNY exchange rates. As described in Section 3.2, the non-normality of the shock process is crucial for the identification of the VIRFs. Hence, we conduct the Jarque-Bera test for both standardised residual series individually in panel B. The null hypothesis of normality is strongly rejected on any significance level, indicating that the residuals are non-normal. Finally, to conduct a meaningful VIRF analysis, the model has to be stable. Stability is a crucial issue in the VIRF analysis, as an unstable model would produce explosive volatility responses. The estimated BEKK model's stability is checked by the three eigenvalues of the  $\mathbf{A}^* + \mathbf{G}^*$  matrix, whereas in Section 3.2 the  $\mathbf{A}^*$  matrix corresponds to the parameter matrix of the equivalent VECH representation for the  $vech(\boldsymbol{\epsilon}_{t-1}\boldsymbol{\epsilon}'_{t-1})$  part, while the  $\mathbf{G}^*$  matrix corresponds to the parameter matrix of the equivalent VECH representation for the  $vech(\mathbf{H}_{t-1})$  part. Since all eigenvalues are in modulus smaller than one, the model is stable, which ultimately enables us to conduct a meaningful VIRF analysis.

Table 1 Posterior means, standard errors, numerical standard errors and model diagnostics for the Bayesian BEKK model

Panel A: Coefficient estimates			
	Mean	Standard error	NSE
$Int_1$	-0.00688371	0.00374305	0.000062
$Int_2$	-0.00533893	0.003456	0.000053
$C_{11}$	0.02400474	0.00143778	0.000019
$C_{21}$	0.00327641	0.00111065	0.000016
$C_{22}$	0.00007765	0.00493578	0.000079
$A_{11}$	0.34130814	0.01451079	0.000216
$A_{12}$	-0.07450192	0.00804046	0.000112
$A_{21}$	-0.19645119	0.01898266	0.000256
$A_{22}$	0.16321999	0.01161006	0.00016
$G_{11}$	0.92247696	0.0019477	0.000024
$G_{12}$	0.02551005	0.00061309	0.000011
$G_{21}$	0.06793894	0.00178964	0.000026
$G_{22}$	0.96947499	0.00078835	0.000013
<i>Acceptance Rate</i>		44.84%	



Panel B: Model diagnostics			
	$R^{USD/CNH}$		$R^{USD/CNY}$
<i>LB-Q(50)</i>	0.5328		0.5132
<i>Jarque-Bera</i>	0.0000		0.0000
<i>Hosking(50)</i>	0.63670		
	<i>Conditional variance of CNH</i>	<i>Conditional covariance</i>	<i>Conditional variance of CNY</i>
<i>Eigenvalues</i>	0.99837	0.97068	0.93133

Notes: Panel A demonstrates the posterior mean, standard deviation and numerical standard error, which is the posterior standard deviation divided by the square root of the number of draws, for the posterior draws of all coefficients of the bivariate BEKK model. The bivariate BEKK model describes the joint volatility dynamics of the filtered return series of the USD/CNH and USD/CNY. The filtering has been conducted via a VAR(11), whose lag length has been selected via AIC. Panel B shows several model diagnostics for the standardised residuals of the BEKK model and the corresponding Eigenvalues of  $A^* + G^*$ .

## 4.2 VIRF analysis

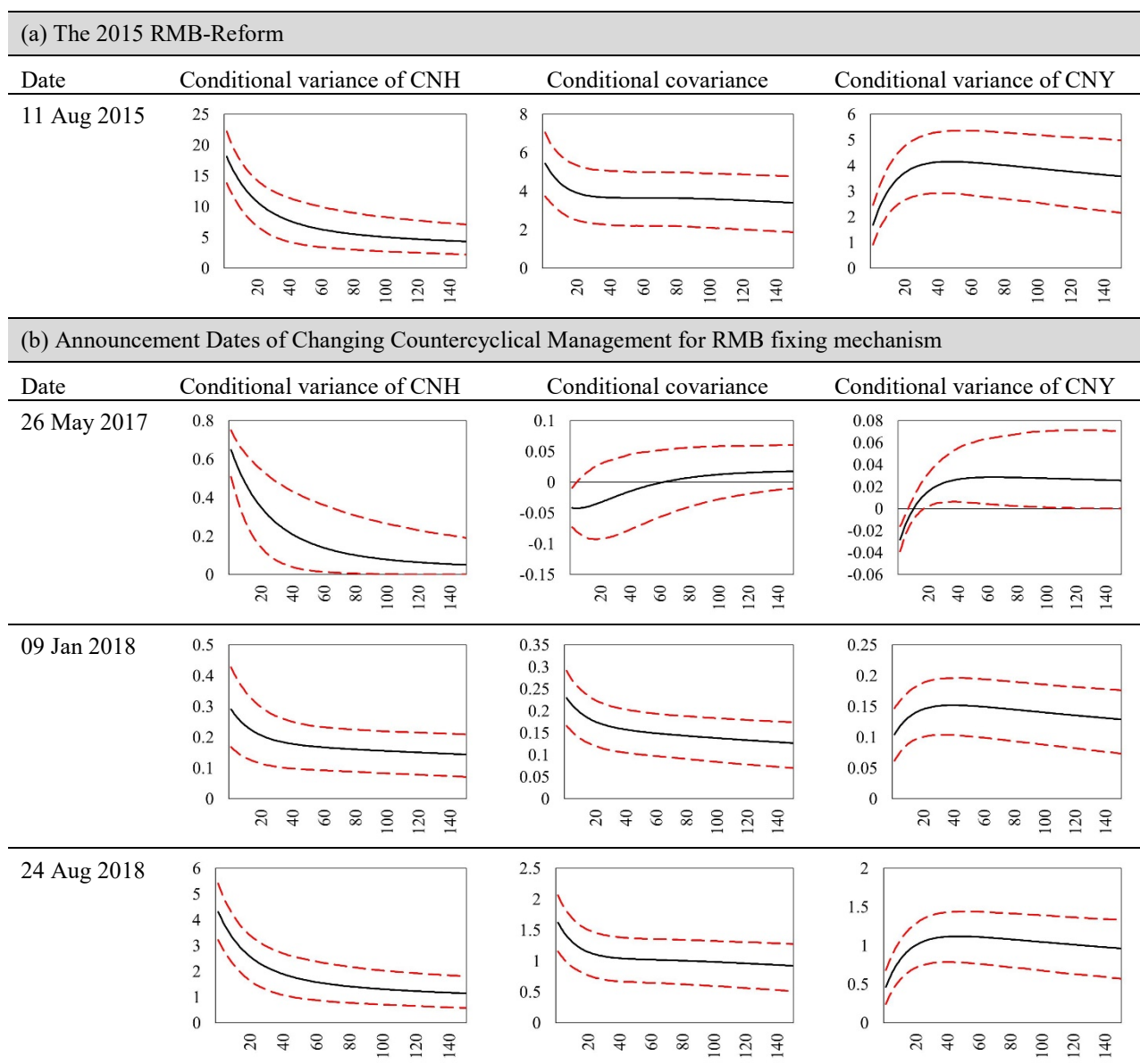
In general, high volatility in the exchange rate always reflects the sudden changes in expectation (West *et al.*, 1993 and Bacchetta and Van Wincoop, 2004). Apart from this, the shock changes the risk appetite, which in turn affects the volatilities of the exchange rates. In Figures 2 – 4, we show the VIRF results for the CNH and CNY exchange rates in view of exchange rate policy shocks, financial market turbulences and the US-China trade conflict in 2018 – 2019. For each shock, there are three VIRF charts. From left to right, they are the impulse response functions for the conditional variance of daily CNH changes, the conditional covariance between changes in the CNH and CNY exchange rates and the conditional variance of daily CNY changes at the date of shocks.<sup>17</sup> In each VIRF chart, the solid lines represent the mean VIRFs up to 150 trading days since the shock, while the dashed lines indicate the corresponding 90% Bayesian confidence intervals. Table 2 summarises the estimated residuals and the VIRF on the selected dates of shocks (time horizon  $t = 1$ ).

### (I) Exchange rate regime changes

It is expected that the exchange rate volatilities increase due to unexpected exchange rate policy changes. In this sub-section, two policy changes are considered, namely the 2015 RMB reform on the fixing mechanism for formulating daily central parity of CNY and the applications of the counter-cyclical factor for the CNY fixing mechanism during May 2017 to January 2018 and again since August 2018.

<sup>17</sup> The filtered return series of the USD/CNH and USD/CNY (in percentages) are used in the estimation. The filtering has been conducted via a VAR(11), whose lag length has been selected via AIC. The impact of a shock is measured by the VIRF on the date that the shock occurred if the shock (or news) happened before the closing of the CNY market. If the shock or news occurred after the closing, the impact will be measured by the VIRF on the next trading day. For shocks occurring during weekends, the VIRF on the next trading day (Monday) will be examined.

Figure 2 VIRFs for the exchange rate regime changes



**Notes:** The solid line is the mean posterior VIRF, while the dashed lines represent the 90% confidence intervals based on 10,000 posterior draws. The values on the vertical axis are expressed in  $e-02$ . The filtered return series of the USD/CNH and USD/CNY (in percentages) are used in the estimation. The filtering has been conducted via a VAR(11), whose lag length has been selected via AIC.

a) The 2015 RMB reform

On 11 August 2015, the PBoC announced the new mechanism (as described in Section 2.1) for formulating the daily central parity fixing of the CNY, as a key step in lobbying the IMF to include the RMB in the Special Drawing Rights (SDR) currency basket.<sup>18</sup> Although the exchange rate regime change only affected the CNY exchange rate, the market participants in both the main and the satellite markets interpreted this as the PBoC's intention to depreciate the RMB exchange rate

<sup>18</sup> In November 2015, three months after the reform, the IMF decided to include the RMB in the SDR basket, and the new SDR basket came into use on 1 October 2016.

(Funke *et al.*, 2017). On the announcement date (11 August 2015), the RMB exchange rates experienced the largest daily depreciation since the adoption of the managed floating regime in 2005. The corresponding VIRFs are shown in panel a of Figure 2. The shock has a significant positive impact on volatilities over 150 trading days (an increase in the CNH and CNY represents depreciation), while, for the time horizon  $t = 1$ , the VIRFs of CNH, the covariance and CNY (expressed in e-02) are 18.118, 5.452 and 1.689, respectively.<sup>19</sup> The VIRF of the CNH exchange rate starts from a higher positive level and then declines slowly, while the CNY's initial VIRF is smaller compared to its offshore counterpart and increases slowly for the next 40 days, approximately. Meanwhile, the covariance trajectory peaks at the beginning and then remains positive and constant over the next 150 trading days. The results show that the shock transmission between the two markets remains significant over time, which points to a feedback loop leading to higher volatility in both markets. Specifically, an initial and sharp rise in CNH volatility leads to increasing volatilities for CNY. Over and above, significantly positive covariance indicates persistently higher volatility in both markets evoked by the feedback loop.

Table 2 Estimated residuals and VIRFs under various shocks

	Estimated residuals (%)		VIRFs on the selected dates of shocks (expressed in e-02)		
	$\Delta \ln(\text{CNH})$	$\Delta \ln(\text{CNY})$	Conditional variance of CNH	Conditional covariance	Conditional variance of CNY
<b>(I) Exchange rate regime changes</b>					
<i>(a) The 2015 RMB reform</i>					
11-Aug-15	2.313	1.846	18.118	5.452	1.689
<i>(b) Announcement dates of changing countercyclical management for RMB fixing mechanism</i>					
26-May-17	-0.355	-0.142	0.649	-0.042	-0.028
09-Jan-18	0.459	0.441	0.291	0.230	0.105
24-Aug-18	-1.250	-1.014	4.317	1.622	0.465
<b>(II) Financial market turbulence in early 2016</b>					
<i>(a) The stock market crash</i>					
04-Jan-16	0.855	0.572	2.509	0.639	0.018
07-Jan-16	-0.158	0.380	0.180	-0.651	0.430
<i>(b) The surge in the interbank interest rate for CNH</i>					
11-Jan-16	-1.266	-0.363	11.523	-0.950	0.027

<sup>19</sup> The central parity fell by 1.9% to 6.2298, marking the largest one-day drop. The CNH and CNY exchange rates fell by 2.3% and 1.9% (until the time the CNY market closed) on that day. Applying the BEKK model, the VIRF is calculated with the estimated residual vector for the returns of exchange rates ( $\Delta \ln(\text{CNH})$ ,  $\Delta \ln(\text{CNY})$ ) (expressed in percentage) was  $\epsilon_0 = (2.313, 1.846)'$  and the estimated volatility state  $\text{vech}(\mathbf{H}_0) = (0.017, 0.013, 0.013)'$ .

	Estimated residuals (%)		VIRFs on the selected dates of shocks (expressed in e-02)		
	$\Delta\ln(\text{CNH})$	$\Delta\ln(\text{CNY})$	Conditional variance of CNH	Conditional covariance	Conditional variance of CNY
<b>(III) The US-China trade conflict</b>					
<i>(a) Announcements of US tightening/threatening measures</i>					
23-Mar-18	-0.455	-0.330	0.583	0.125	-0.010
29-May-18	0.370	0.285	0.286	0.087	-0.015
06-May-19	0.569	0.477	0.706	0.325	0.071
02-Aug-19	0.916	0.599	3.621	0.526	0.053
06-Aug-19	-0.551	-0.454	-0.021	0.330	0.059
<i>(b) Announcements of Chinese retaliation measures</i>					
02-Apr-18	-0.119	-0.078	-0.271	-0.032	-0.056
03-Jun-19	-0.144	-0.034	-0.118	-0.071	-0.051
17-Jul-19	0.024	-0.039	-0.151	-0.072	-0.040
02-Sep-19	0.111	0.169	-0.391	-0.061	-0.032
<i>(c) Trade conflict turning points</i>					
03-Dec-18	-1.033	-1.110	1.640	1.325	1.022
01-Jul-19	-0.184	-0.233	-0.167	-0.014	0.006
14-Oct-19	-0.093	-0.269	-0.461	-0.083	0.055
16-Dec-19	0.046	0.091	-0.513	0.001	-0.050

Notes: The VIRF on the selected dates of shocks (time horizon  $t=1$ ) is the mean posterior VIRF based on 10,000 posterior draws. The filtered return series of the USD/CNH and USD/CNY (in percentages) are used in the estimation. The filtering has been conducted via a VAR(11), whose lag length has been selected via AIC.

#### b) Countercyclical factor for RMB fixing mechanism

Another important RMB regime change is the introduction of the countercyclical factor into the CNY exchange rate fixing mechanism (McCauley and Shu, 2019). The PBoC introduced this amendment to the CNY exchange rate fixing mechanism in May 2017. Initially, the change was difficult to assess. The change initially caught market participants by surprise. An explanation was then provided in the PBoC's Quarterly Monetary Policy Report published in August 2017. Since then, the market participants treated the introduction of the countercyclical factor as a signal of the PBoC's intention to strengthen the RMB exchange rate.<sup>20</sup> Panel b of Figure 2 shows the VIRFs for three announcement dates of the introduction/removal of the countercyclical factor.

At the initial introduction of the countercyclical factor in the CNY fixing mechanism, the VIRFs of the CNH, the covariance and the CNY (expressed in e-02) are 0.649, -0.042 and -0.028, respectively. There is only a mild initial increase (only one-thirtieth of the impact of the shock of the 2015 RMB Reform) in the variance of the CNH, and the impact declines gradually. The initial impact on the covariance is negative, but the impact is only significant in the first three trading days

<sup>20</sup> Actually, before the modification, other major currencies and some emerging market currencies had significantly appreciated against the USD, while the RMB exchange rate appreciated only slightly against the USD. Specifically, in the first five months of 2017, many currencies significantly appreciated against the USD, for example, the euro (6.91%), the Japanese yen (5.58%), the British pound (4.46%), the Australian dollar (3.08%), the Russian ruble (8.31%), the Indian rupee (5.29%), the Mexican peso (11.32%), and the South African rand (4.74%). However, during the same period, RMB only appreciated 1.07% against the USD. The PBoC suggested that the USD/CNY exchange rate deviated from the economic fundamentals, which was dominated by the speculation on RMB depreciation. Therefore, including the countercyclical factor in the CNY fixing mechanism could help the central parity to reflect the changes in fundamentals of the economy and to offset procyclical volatilities in the foreign exchange market (see PBoC Monetary Policy Report 2017 Q2).

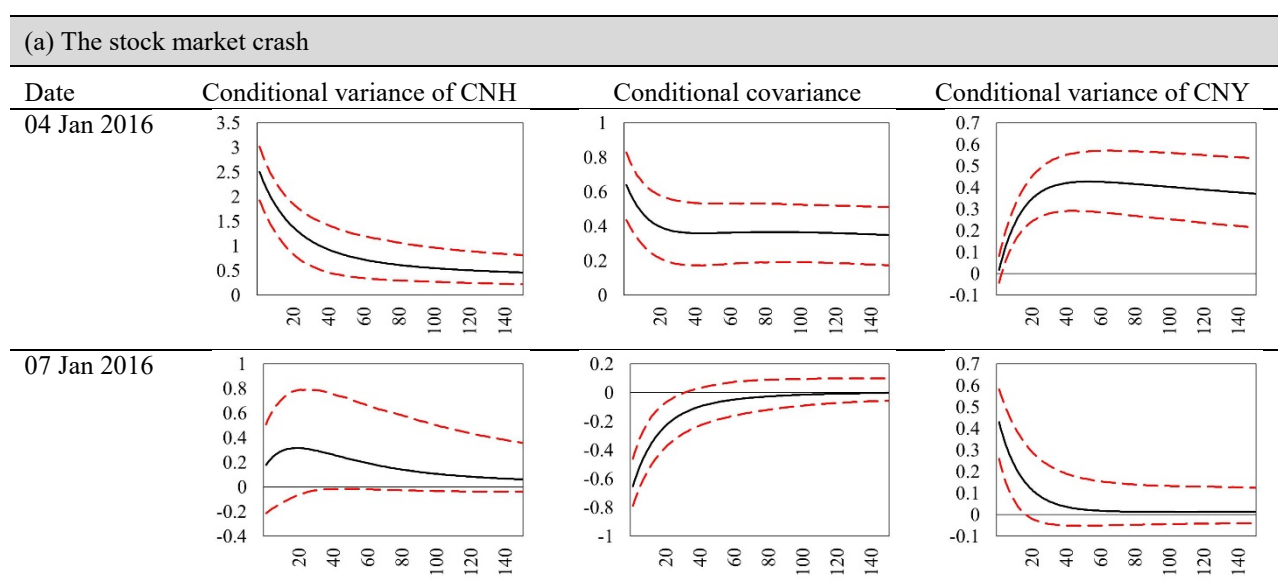
and then turns insignificant. The variance of CNY declined mildly at the beginning, but the impact is only significant in the first six trading days and then turns insignificant. Lacking enough information on the new policy, market participants did not revise their expectations after the initial announcement, and the insignificant covariance shows that there was no volatility transmission between the two markets.

The countercyclical factor was removed from the CNY fixing mechanism in January 2018 but re-introduced again in August 2018. The VIRFs at both regime change announcements are significant. The market participants interpreted the introduction (removal) of the countercyclical factor as a signal to appreciate (depreciate) the RMB exchange rate. For the last two announcement dates, the average VIRFs of the CNH, the covariance and the CNY (expressed in e-02) are 2.304, 0.926 and 0.285 respectively. Over the 150-trading-day horizon, the VIRFs of the CNH and the covariance start from a positive level and then decline slowly. At the same time, the initial VIRFs of the CNY are smaller than its satellite counterpart. For these two shocks, the profiles of CNH volatilities and the co-volatilities are very similar. Similar to the 2015 RMB reform shock, the results suggest that the main direction of shock transmission is from the CNH exchange rate to the CNY exchange rate.

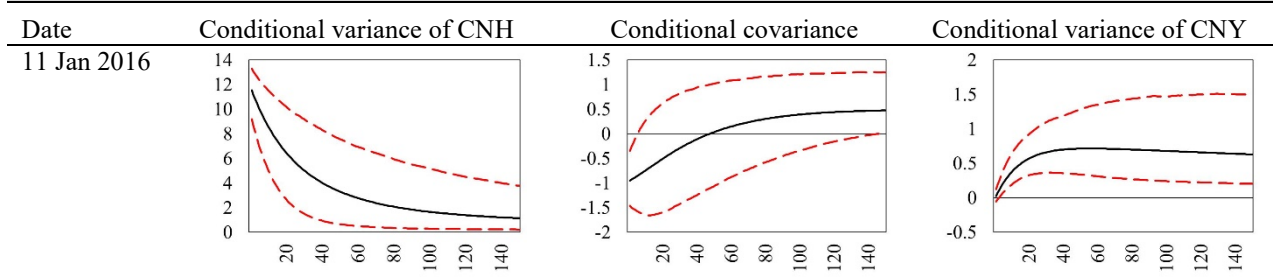
## (II) Financial market turbulences

In principle it can be expected that financial market turbulences evoke larger exchange rate fluctuations. This is especially true for negative shocks, as these may trigger capital outflows. Figure 3 shows the impact of selected stock market shocks as well as the offshore CNH interbank interest rate surge in early 2016 on the volatilities and the spillovers of the main and satellite RMB exchange rate markets.

Figure 3 VIRFs for financial market turbulence in early 2016



(b) The surge in the interbank interest rate for CNH



Notes: The solid line is the mean posterior VIRF, while the dashed lines represent the 90% confidence intervals based on 10,000 posterior draws. The values on the vertical axis are expressed in  $e-02$ . The filtered return series of the USD/CNH and USD/CNY (in percentages) are used in the estimation. The filtering has been conducted via a VAR(11), whose lag length has been selected via AIC.

a) The stock crash in early 2016

In response to the increasingly volatile stock markets in the second half of 2015, the China Securities Regulatory Commission (CSRC) introduced a circuit-breaker system in January 2016. Already on the first trading day of the introduction of the system, 4 January 2016, the market closed as the trade suspension mechanism was triggered (7% drop in the Shanghai-Shenzhen 300 Index). The trade suspension mechanism was triggered once again on 7 January 2016. Finally, as the new system appears to have increased the negative market sentiment, it was removed on 8 January 2016. The VIRF analysis is applied to both trading interruptions to examine the impact of stock market turbulence on the main and satellite RMB exchange rate markets.

The trading suspension occurred on the first day of the introduction of the new mechanism (4 January 2016), which threatened the market. Given the concern of an accelerating capital outflow after the official foreign exchange reserves had declined for more than one year, the stock market turbulence elevated the volatilities in both RMB exchange rate markets. The VIRFs of the CNH exchange rate, the covariance and the CNY exchange rate (expressed in  $e-02$ ) are 2.509, 0.639 and 0.018, respectively. The VIRFs are significant for almost 150 trading days. Specifically, the VIRFs of the CNH exchange rate and the covariance start from a higher positive level and then decline slowly. Given the tightly managed onshore RMB market, the impact on the onshore exchange rate was smaller and slower than that of the offshore counterpart. The initially insignificant CNY VIRFs only turned significant over time. In comparison, the offshore market reacted faster and stronger. Furthermore, there is a significant transmission between the two markets as indicated by the significant covariance trajectory.

In contrast, the VIRFs are mostly insignificant for the shock on 7 January 2016. The results reflect the nature of the VIRFs: impacts are conditional upon information up to the date of the shock. As the two shocks are essentially the same, the information was already priced into the VIRF reaction on 7 January. Therefore, market expectations have not been changed, explaining the comparatively unresponsive VIRFs (including the weak impact on co-volatility) on 7 January.

### b) The surge in the interbank interest rate for CNH

After the stock market turbulence in the first week of 2016, there was a heavy depreciation pressure on the RMB exchange rate. The presumed desire for an RMB devaluation was exaggerated by the short-selling in the offshore CNH market. On 11 January 2016, the sole interbank RMB liquidity provider, Bank of China (Hong Kong), did not provide the funding in the market. As a consequence, the CNH HIBOR (Hong Kong interbank offered rate for CNH) recorded an unexpectedly sharp rise, and the expectation of a continued depreciation in the RMB exchange rate was revised.<sup>21</sup> As a result, the CNH and the CNY exchange rates appreciated by 1.29% and 0.36%, respectively on 11 January 2016. This result is consistent with the literature emphasising that central bank interventions increase the volatility of exchange rates (Dominguez, 1998).

The VIRFs of the CNH, the covariance and the CNY (expressed in e-02) are 11.523, -0.950 and 0.027 respectively. The CNH's VIRF starts from a significantly higher positive level and then declines gradually. The initial VIRF of CNY is positive and insignificant, but the impact turns to significance from the third trading day onwards. The covariance trajectory is negative and significant in the first five trading days and then also turns insignificant. The results illustrate the absence of a shock transmission across markets.

### (III) The US-China trade conflict

For a long time, the United States has been China's largest trading partner. The immediate consequence of this is that American-Chinese trade conflicts are expected to have repercussions on the exchange rate. Table 3 summarises major episodes of the US-China trade tensions between 2018 and 2019.<sup>22</sup> In this subsection, the episodes are classified in three categories: (i) US shocks – dates when the US announced the introduction or elevation of import tariffs; ii) China shocks – the dates when China's retaliations were announced; and iii) turning points – the dates at which a calming of the situation seemed possible. In the following, we apply the VIRF analysis to evaluate to what extent selected episodes and news of the US-China trade conflict between 2018 and 2019 have affected the volatilities and spillovers of the main and satellite RMB exchange rates.

<sup>21</sup> In particular, on 11 January 2016, the overnight CNH HIBOR increased sharply by 939 basis points from 4% to 13.4% and further increased to 66% on the next trading day.

<sup>22</sup> For a US-China trade conflict timeline, see <https://www.piie.com/blogs/trade-investment-policy-watch/trump-trade-war-china-date-guide>.

Table 3 Major episodes of the US-China trade conflict

Date of announcement	Date of analysis	Classification	Episode
22 Mar 2018	23 Mar 2018	US shock	Trump asked the US trade representative (USTR) to investigate the USD 50–60 billion of tariffs applied on Chinese goods.
2 Apr 2018	2 Apr 2018	China shock	In response to Trump's threatening, China's Ministry of Commerce suggested imposing tariffs on 128 products imported from the US.
29 May 2018	29 May 2018	US shock	The White House announced that it would impose a 25% tariff on \$50 billion of Chinese goods with "industrially significant technology".
1 Dec 2018	3 Dec 2018	Turning point	After the meeting of Trump and Xi Jinping, the US and China agreed to postpone the planned tariff increases and begin another round of negotiations.
5 May 2019	6 May 2019	US shock	Trump stated on Twitter that the US would raise the tariff from 10% to 25% on USD 200 billion of Chinese goods.
1 Jun 2019	3 Jun 2019	China shock	China announced raising tariffs on USD 60 billion of US goods.
29 Jun 2019	1 Jul 2019	Turning point	During the G20 Osaka summit, Trump and Xi Jinping agreed to have further negotiations. The existing tariffs would be still in effect, but the plan of further tariffs is temporarily paused.
17 Jul 2019	17 Jul 2019	China shock	China announced an accelerated decrease in holdings of US treasury holdings, with a target of a 25% decrease of its holdings of USD 1.1 trillion.
1 Aug 2019	2 Aug 2019	US shock	Trump announced that the US would levy an additional 10% tariff on the "remaining \$300 billion of goods" from China.
5 Aug 2019	6 Aug 2019	US shock	The US Department of Treasury officially declared China as a currency manipulator.
2 Sep 2019	2 Sep 2019	China shock	China has brought a lawsuit to the WTO to challenge US tariffs against USD 300 billion of Chinese exports.
11 Oct 2019	14 Oct 2019	Turning point	Trump announced that China and the US had reached a tentative "first phase" trade deal and the US would suspend new tariffs scheduled on 15 October 2019.
13 Dec 2019	16 Dec 2019	Turning point	Both countries announced an initial deal, and new tariffs planned to be imposed on December 15 would not be implemented.

Note: The date of analysis is defined as i) the date that the shock occurred if the shock (or news) happened before the closing of the CNY market; ii) the next trading day of the shock occurred if the shock or news occurred after the closing or the shock occurred during the weekend.

Sources: Wong and Koty (2020), "The US-China trade war: A Timeline, China Briefing" (<https://www.china-briefing.com/news/the-us-china-trade-war-a-timeline/>) and Wikipedia, "China–United States trade war" ([https://en.wikipedia.org/wiki/China%E2%80%93United\\_States\\_trade\\_war](https://en.wikipedia.org/wiki/China%E2%80%93United_States_trade_war)).

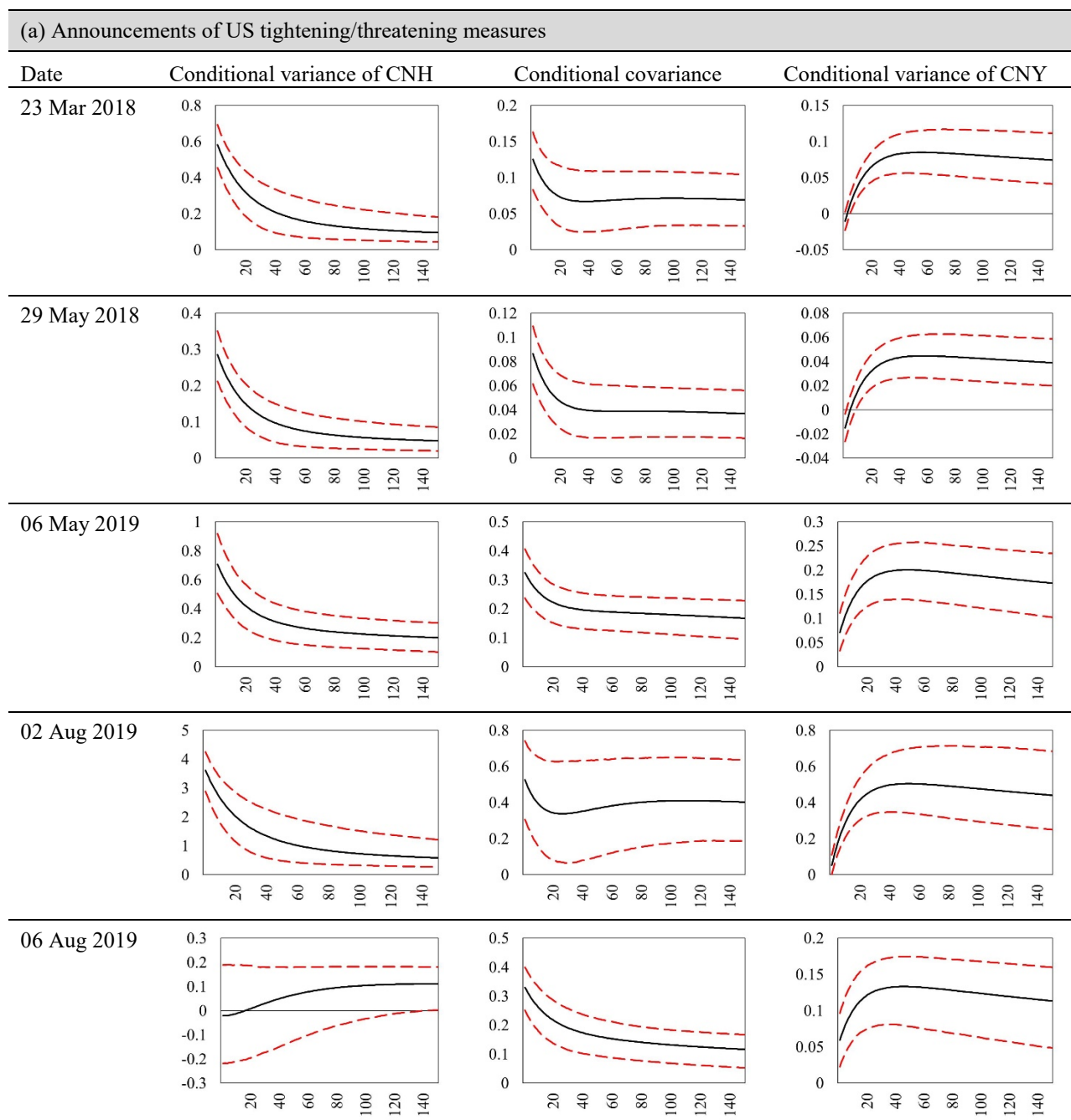
#### a) Announcements of US tightening/threatening measures (US Shocks)

Panel a in Figure 4 reports the VIRFs of the US shocks. In general, the VIRFs of the US shocks are significant over most of the 150 trading days, except the shock on 5 August 2019. The US classified China as an exchange rate manipulating country on 5 August 2019 (in the afternoon, New York time). Given the previous devaluation of the RMB, this statement had been anticipated. For the other four US trade shocks, the average VIRFs of the CNH, the covariance and the CNY (expressed in  $e-02$ ) are 1.299, 0.266 and 0.025, respectively (if for all five US shocks only, the numbers are 1.035, 0.279 and 0.032). For the first four US shocks, the VIRFs of the CNH and the covariance start from a higher positive level (compared to the CNY) and then decline slowly. The initial CNY's VIRF is

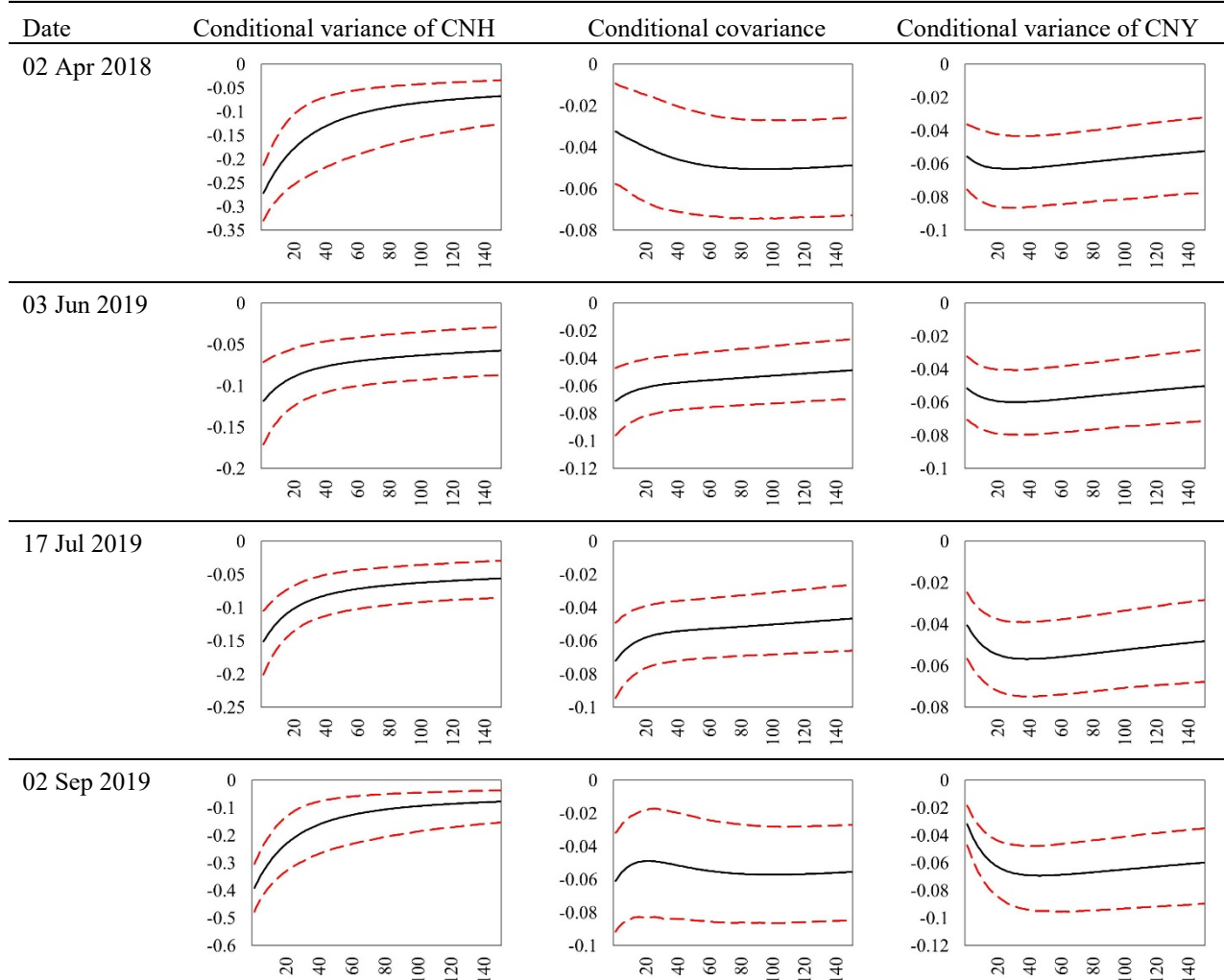


negative and insignificant, but the impact then increases and becomes significant. Together with the significant covariance, these results illustrate that the CNH reacts faster and is more responsive to the US shocks during the US-China trade conflict and then gradually triggers changes of the CNY exchange rate. These results demonstrate that the US shocks have triggered and exaggerated an expectation of RMB depreciation. Furthermore, the RMB volatilities and the spillover effects between the main and satellite markets strengthened.

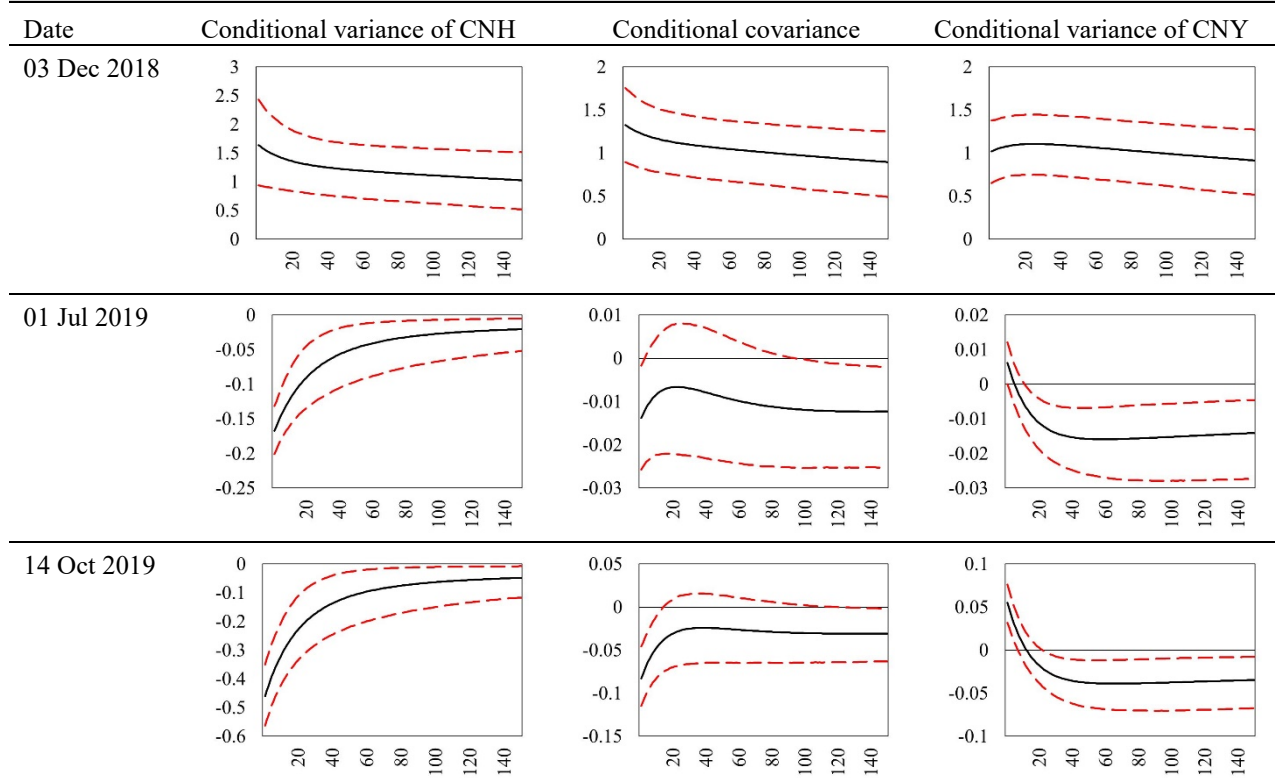
Figure 4 VIRFs for the US-China trade conflict

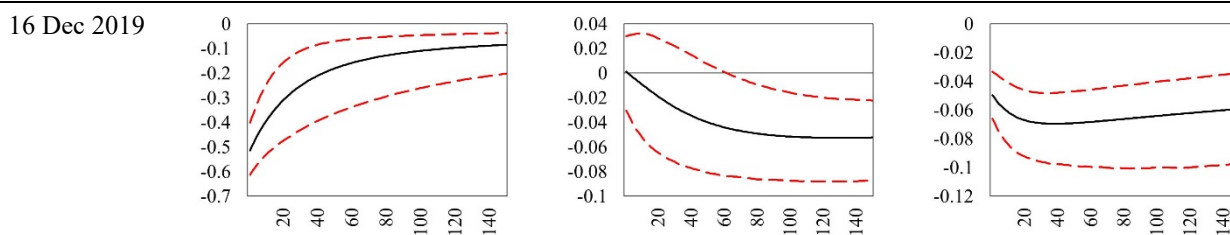


(b) Announcements of Chinese retaliation measures



(c) Trade conflict turning points





Notes: The solid line is the mean posterior VIRF, while the dashed lines represent the 90% confidence intervals based on 10,000 posterior draws. The values on the vertical axis are expressed in  $e-02$ . The filtered return series of the USD/CNH and USD/CNY (in percentages) are used in the estimation. The filtering has been conducted via a VAR(11), whose lag length has been selected via AIC.

#### b) Announcements of Chinese retaliation measures (China Shock)

The VIRFs of the China shocks are shown in Panel b of Figure 4. For all China shocks, all VIRFs of the CNH, the covariance and the CNY are negative and significant over most of the 150 trading days. In other words, the conflict-induced increase in the RMB volatilities was mitigated by China's retaliation measures. The literature suggests that trade deficit shocks typically increase the exchange rate volatility (Madura and Tucker, 1992; Sultan, 1994 and Neely, 2011). However, trade deficit-increasing and trade deficit-decreasing shocks may have asymmetric effects (Sultan, 1994). A plausible explanation for the declining volatility is thus the expectation that the retaliation measures will mitigate the impact of the trade tensions upon the Chinese economy. It is also consistent with the declining co-volatilities. For all four China shocks, the average initial VIRFs of CNH, the covariance and CNY (expressed in  $e-02$ ) are  $-0.233$ ,  $-0.059$  and  $-0.045$ , respectively.

#### c) Trade conflict turning points

Panel c of Figure 4 presents the VIRFs of four turning points of the US-China trade conflict. The first turning point was the 1 December 2018 (Saturday) when the US and China agreed to postpone the reciprocal tariff increases and to re-open trade negotiations. This was a major policy change after months of high tensions between both countries. Accordingly, this shock had significantly altered the RMB exchange rate. On 3 December 2018 (the first trading day after 1 December 2018), the initial VIRFs of the CNH, the covariance and the CNY (expressed in  $e-02$ ) are 1.640, 1.325 and 1.022 respectively. All VIRFs of the CNH, the covariance and the CNY for the selected turning points in the US-China trade conflict are positive and significant over most of the 150 trading days. A different picture emerges for the other three selected points in time. In each case the VIRFs of the CNH, the covariance and the CNY are negative and significant over most of the 150 trading days. This indicates the calming of the situation.

## 5 Conclusion

The estimation results demonstrate the usefulness of the novel Bayesian estimation VIRF tool in examining the main and the satellite RMB market dynamics and their interplay. Particularly noteworthy is the possibility of calculating confidence intervals. The VIRF estimation results illustrate that both exchange rates have different characteristics. The satellite CNH exchange rate is characterised by faster and stronger responses to the different shocks compared to its onshore counterpart. This differing time profile leads to a transmission of shocks delayed by 3–5 days. The VIRF shock profiles also show that the CNH market plays the price discovery role of the RMB exchange rate (see Maziad and Kang, 2012 and Wang and Wang, 2017) which may be used for forecasting purposes.

Economists agree that getting the exchange rate regime right is essential for economic growth and safeguarding economic stability. Typically, the choice of an appropriate exchange rate regime consists of the selection of an exchange rate regime along the fixed (or pegged) versus intermediate (or target zone) versus flexible (or independently floating) continuum of exchange rate regimes. For example, in the 1980s and the 1990s, freely floating exchange rates were quite popular. This prevailing trend towards more flexible exchange rate regimes was associated with more open policies on trade and foreign direct investment. However, after the Asian financial crisis 1997–1998, Calvo and Reinhart (2002) identified a “fear of floating”. Meanwhile, other observers suggested intermediate regimes like target zones which might combine the advantages of freely floating and absolutely fixed exchange rates (see, e.g., Masson, 2001). In contrast, China is a special case. From the traditional point of view, it is apparent that China has adopted a unique strategy of its own by means of having simultaneously two exchange rates with very different characteristics: the onshore CNY and the offshore CNH. The co-existence of opposing exchange rate regimes and their interplay opens up unique new economic policy prospects for shaping and balancing the trade-offs between liberalisation and protection as well as stability and flexibility in a time-variable manner.<sup>23</sup> It remains to be seen whether other countries will adopt similar parallel currency regimes in the future.

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<sup>23</sup> These advantages are counterbalanced by the fact that speculators may use the CNH to bet against the RMB. Prevailing pricing differentials between the two exchange rates made interventions both on the mainland and in the offshore market necessary and demonstrated the costs of such a dual exchange rate regime.

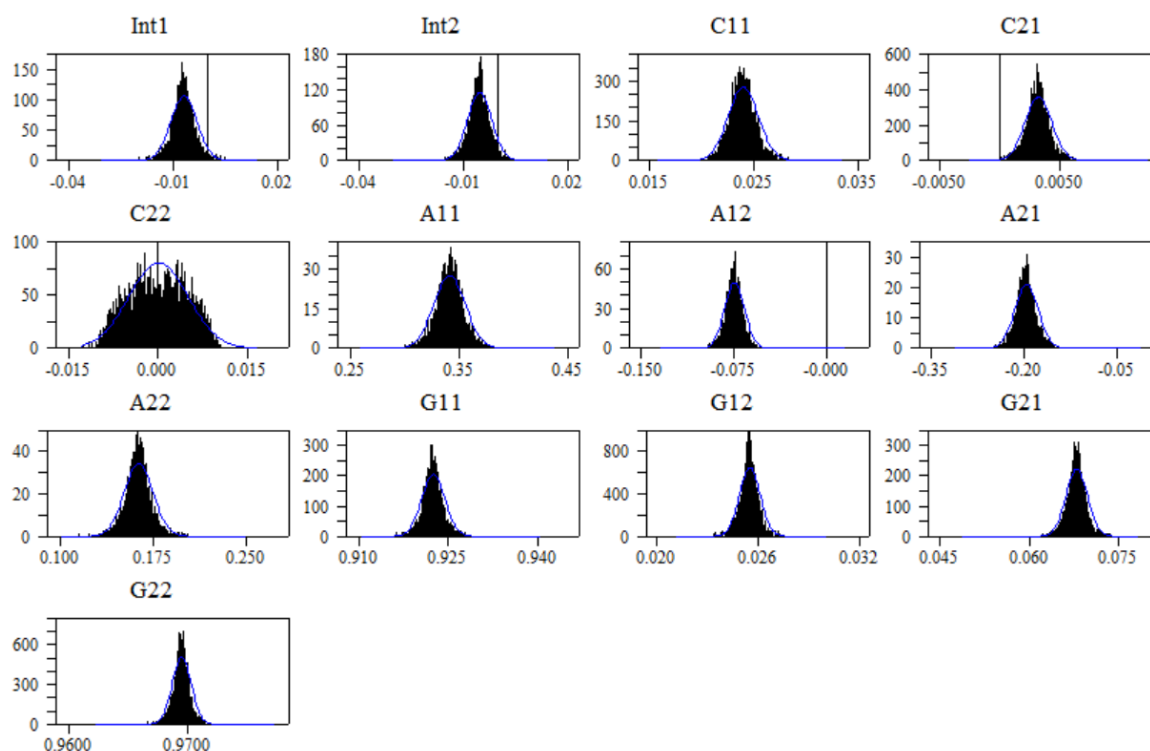
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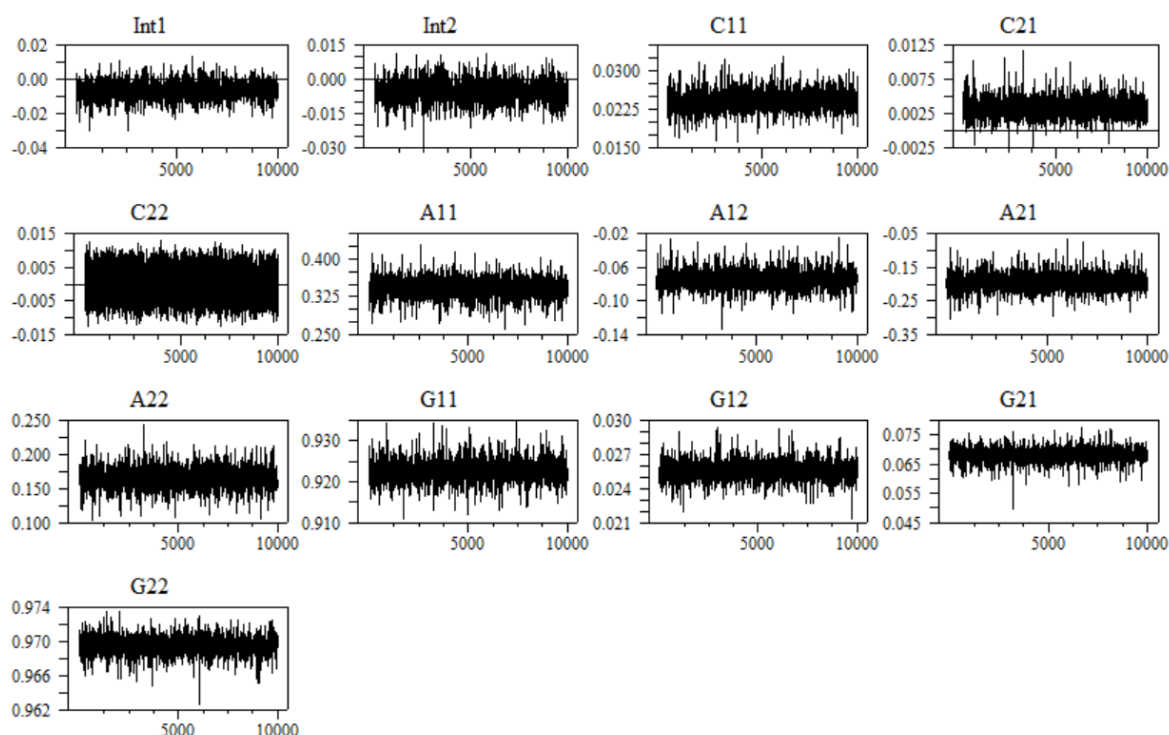
## Appendix: Convergence

Figure A1 Posterior of coefficients of the BEKK model



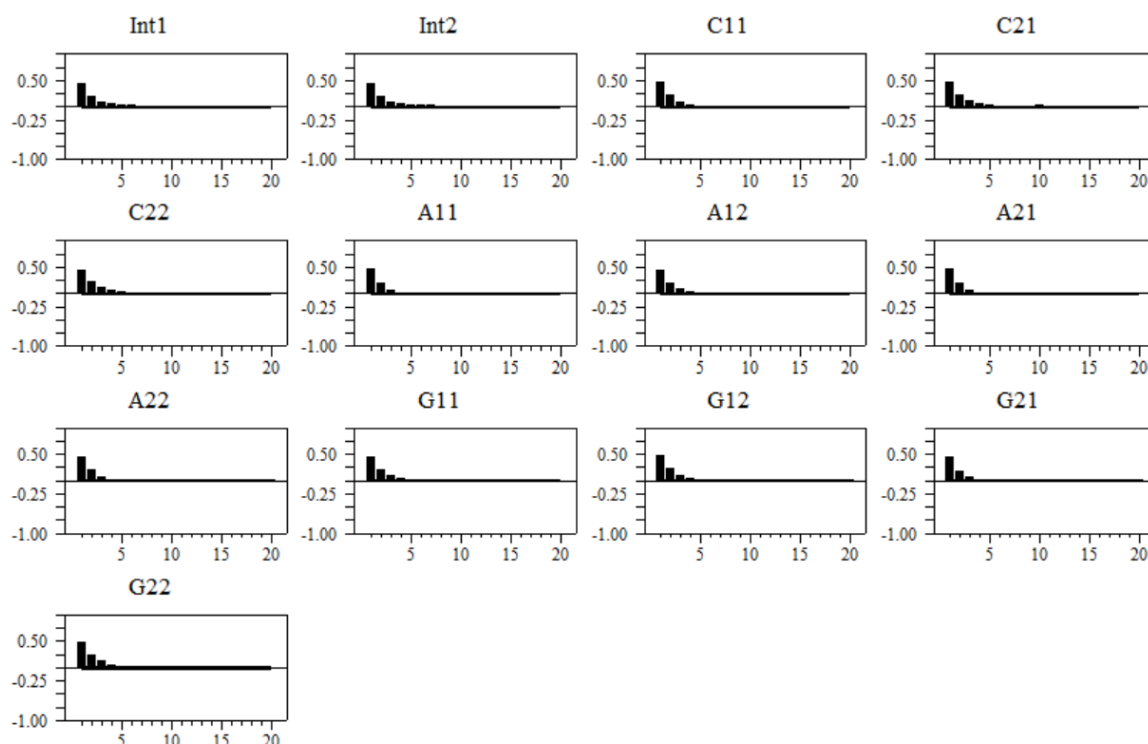
Notes: This figure displays the histogram and kernel density estimate of the posterior draws after the burn-in sample has been discarded.

Figure A2 Trace plots of posterior draws of the BEKK coefficients



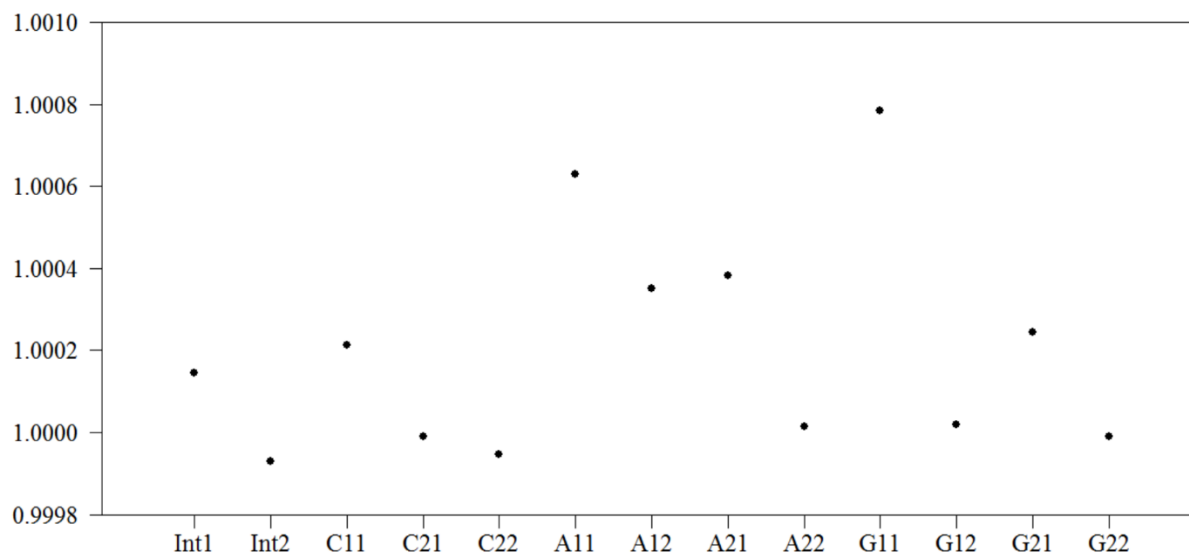
Notes: This figure displays the trace plots of the posterior draws after the burn-in sample has been discarded.

Figure A3 ACF of the posterior draws of the BEKK coefficients



Notes: This figure displays the ACF of the coefficient draws presented in the trace plots in Figure A2. The draws are without the burn-in sample.

Figure A4 Gelman-Rubin diagnostic of the BEKK coefficients



Notes: The diagnostic is calculated for three different series of draws (after burn-in) for every single BEKK coefficient. The three separate Markov chains have been simulated with different starting values. Two of the chains are initialised by the QML estimates plus a draw from a multivariate t-distribution with the same degrees of freedom and scale matrix as described in Section 3.3, multiplied by 10,000 to get starting values which are far off the starting values for the ICMH sampler in the main part. The GR Diagnostic compares the within-sequence variance with the between sequence-variances of the different chains. Values close to one indicate convergence. Every value below 1.2 is considered as converged.



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